Gas Technical Regulators Committee

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Gas Appliance (Carbon Monoxide) Safety Strategy

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EXECUTIVE SUMMARY

The move to greater thermal efficiency in buildings has resulted in dwellings becoming increasingly "air tight". At the same time there has been a tendency to install an increased number of exhaust fans. This combination of reduced ventilation combined with powerful exhaust fans has resulted in a situation where dwellings, or part thereof, can be exposed to air pressure substantially lower than the outside atmosphere, often termed "negative pressure". When a conventionally flued natural draught gas appliance is operated in an area under negative pressure this can result in reverse flow in the flue. In this scenario outside air is drawn in through the flue and, rather than the flue products being discharged to the outside, they are "spilled" into the indoor environment through the appliance draught diverter. If the appliance is producing high levels of carbon monoxide (CO) either inherently or as a result of the down draught, this can lead to unacceptably elevated indoor concentrations of CO, which may present a substantial health hazard.

Reverse flow in an appliance flue is termed "adverse flow", as opposed to "normal" flow. In US literature the term "backdrafting" is used. It has been extensively studied by the UK Health and Safety Executive (HSE) and is widely recognised as a potential problem, particularly with the tightening of dwellings and the prevalence of exhaust fans noted above. Adverse flow can also be triggered by wind conditions but, as might be expected, wind tends to be intermittent in its speed and direction and is so less likely to create extended periods of adverse flow as might occur with a continuously operating exhaust fan.

Adverse flow can occur either when an operating appliance is exposed to negative pressure (such as by the turning on of an exhaust fan in an area of restriction of ventilation) and the normal flow is reversed or by an appliance being started under pre-existing conditions of negative pressure and normal flow in the flue not establishing or taking excessively long to do so. The latter case (failure to establish normal flow) is typically more susceptible to negative pressure than the former (reversing an established normal flow).

While there is some variance in the literature, reported values necessary to cause adverse flow (from as little as one to a few Pascals) are all much lower than the negative pressure capability of a typical modern exhaust fan in a space with limited ventilation. This was also found to be the case in the work commissioned by the Energy*Safety* Division of the Western Australian Department of Commerce and conducted by the Australian Gas Association (AGA) at its Melbourne laboratory and reported in Appendix B.

The results of the AGA tests and the literature both point to a developing problem where air tight houses and exhaust fans are used in combination with conventionally flued natural draught appliances. A review of the current applicable codes and standards indicates that they do not adequately address this issue.

This report follows well established risk mitigation methods. It ranks the controls from preferred (i.e. elimination, of the hazard and proper engineering controls) to non preferred (procedural controls). The points below summarise a range of controls that are discussed in detail further in the report. There are already a range of preferred controls in use in the gas industry such as: the use of certified appliances, Australian Appliance Standards, licensed gas fitters and gas technical and safety regulations. New developments in the building construction techniques have their effect on the pressure envelops of dwellings and whilst this has been recognised in overseas construction/ventilation codes further development of the national construction code is recommended to bring it into line with overseas codes. Other preferred risk mitigation techniques such as: appliance type selection, minor improvements in the natural draught appliance standards and improved maintenance of appliances in the field should all be implemented well before non-preferred controls are considered.

A range of possible remedial actions have been considered and are briefly summarised below:-

1. The use of CO alarms is not favoured in residences because alarms are a non-preferred procedural control. In addition, there are issues relating to their reliability, useful life, functionality (number required), positioning, cost and because they are not linked into the gas supply of the appliance and so cannot effect a cut off. To incorporate such a link would require a more complex design with significant manufacturing modifications and cost implications. The cost of installing mains powered CO alarms without links to the interruption of gas supplies would be in the order of 3.5 to 4 billion dollars.
2. Over a 10 year period the cost of the initial installation and ongoing replacement of alarms with gas supply interruption capability would be around $12B. Over such 10 year period an estimated 10 fatalities would have occurred due to CO poisoning, mostly in residences. While a Quantitative Risk Assessment would be required, it is not anticipated that expending around $1.2B to $1.5B per potential fatality represents optimal value for the community.
3. The installation of CO alarms in recreational vehicles appears to be more cost effective, but even that represents an expenditure of $100M per potential fatality.
4. Temperature actuated spill switches linked into the gas supply will shut down the appliance in the event of a flue blockage or partial flue blockage. However, in the event of a strong adverse flow and the consequent large dilution of the combustion products, spill switches are not likely to be effective due to the low temperature of the spilled gas.
5. Increasing the ventilation (free area of ventilators directly leading to the outside) can reduce the tendency for adverse flow to develop but may be incompatible with requirements to improve the thermal efficiency of buildings (such as under the 6 Star Rating scheme). Due to the small pressures required to affect the flue flow, the ventilation area would need to be large.
6. Oxygen depletion sensors (ODS) have a metastable pilot flame which extinguishes if the level of vitiation of the combustion air becomes excessive. However, an ODS is an inferential device and may not provide protection in a case where an appliance was spilling combustion products containing an excessively high concentration of CO. Also retrofitting ODS's into existing appliances on the scale required appears impractical.
7. Appliance maintenance is recommended for all gas appliances every two years and, while not a measure to prevent or limit the development of negative pressures, it should ensure that CO emission from appliances so maintained is minimised. Mandating the servicing of gas appliances would be effective in reducing the likelihood of a hazardous situation developing. Practically, however, this would only be applied to rental properties.
8. The use of room sealed or forced draught appliances would ensure protection against the spillage of combustion products into living areas. However such appliances are expensive and retrofitting them in place of existing installations is impractical.
9. Timers inserted in the electrical circuit of the exhaust fan(s) appear to be a viable option in reducing the possibility of extended periods of negative pressure caused by fan operation. However such a control does not physically interrupt the gas flow and may be seen as an inconvenience by users.
10. A public awareness campaign on the potential hazards of situations in which negative pressures are developed, while not effecting any physical protections, would be a method of raising public awareness of the potential hazard of operating an exhaust fan(s) simultaneously with a conventionally flued natural draught gas (or other combustion) appliance. The campaign may include bill inserts and stick-on notices as well as newspaper advertising.

11. It is estimated that there are 4.2 million dwellings in Australia where the possibility of negative pressure conditions affecting combustion appliances exists.

In relation to point 11 the following additional comments can be made:

- Addressing the higher priority safety related items (engineering controls) is in accordance with recognised engineering risk mitigation techniques. It also avoids the issues associated with professional liability aspects of addressing lower ranked procedural controls (such as CO alarms without interruption to gas supply) prior to the implementation of engineering controls. To illustrate the point, if a CO related fatality were to occur in a dwelling fitted with CO alarms then a subsequent coronial inquiry would most likely consider the risk model followed. CO alarms being a non-preferred control, also given the technical difficulties in their application and when used in isolation to other controls are not likely to reduce the potential of CO fatalities substantially. If it is then established that such non-preferred controls were (only) implemented the coroner would be well justified in making negative findings against the individuals who implemented such in appropriate risk model.
- Implementing CO alarms overseas was only introduced after; other, more effective means of achieving safety outcomes were pursued. These include improvements in appliance maintenance, appliance types and ventilation.

In summary, it is recommended that a consultancy with access to suitably qualified personnel should be engaged to review the relevant literature, including the present report, and produce a quantitative risk assessment of the issues relevant to the effect of negative pressures in buildings where conventionally flued natural draught gas appliances are in use.

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1 INTRODUCTION

Following a well documented incident in Victoria the Gas Technical Regulators Committee (GTRC) chair, currently Energy*Safety* in WA, carried out a risk assessment and identified the potential for carbon monoxide (CO) poisoning to be caused by the operation of an air exhaust fan(s) where a conventionally flued natural draught gas appliance is used. Meanwhile, the Honourable Dr. Sharman Stone MHR put forward a motion within the Commonwealth House of Representatives that the Australian government work through the Council of Australian Governments (COAG) to task the Ministerial Council on Energy (MCE) to work with state and territory gas safety regulators to mitigate the risks of carbon monoxide poisoning from household gas appliances by developing a strategy that explores options that may mitigate the risks of carbon monoxide poisoning from household gas appliances. This proposal led to the former Ministerial Council on Energy (now the Standing Council on Energy and Resources (SCER) approaching the chair of the GTRC with a request to provide this strategy document. For further information about the report you may contact Mr. Cornelis de Groot, Chair of GTRC on 08 9422 5200 or by email cornelis.degroot@commerce.wa.gov.au.

Terms of reference for the development of the Gas Appliance (Carbon Monoxide) Safety Strategy (the Strategy) were developed by MCE officials in consultation with the GTRC having regard for the scope proposed in the parliamentary motion and input from the MCE. The scope of the Strategy was expanded to consider causes and mitigation options to address recognised risks associated with carbon monoxide poisoning in recreational vehicles

This document identifies a series of factors that influence safety outcomes and provides a perspective that these factors play in safety outcomes in residences. They include, but are not limited to, appliance types (in particular conventionally flued natural draught appliances), improved energy efficiency, CO detection, exhaust fan installation practices and Australian and overseas building codes.

The report considers the causal aspects which include appliance type, flueing, appliance maintenance and industry practices and codes. The report also considers controls and these include improved ventilation and appliance maintenance, appliances design and CO detection. CO detection (without linkage into the gas supply) is not considered a physical control as it only provides an indication of a problem.

While the entire GTRC are involved in this strategy, major contributions to this document were from Western Australia, Victoria and South Australia. The Victorian input focuses on CO detection and alarms while the Western Australian effort concentrates on gas appliance and exhaust fan issues in residences. The South Australian focus was on CO issues in recreational vehicles.

Exhaust fans can cause a negative or sub-atmospheric pressure in the building envelope with respect to the external atmosphere. If the air supply to a residence is inadequate such negative pressures may be sufficient to cause a reversal of the normal flue flow direction; air enters the residence through the flue rather than products being expelled and combustion products are spilled into the indoor environment. This condition is termed adverse flow. This is particularly the case in air tight houses and there is substantial evidence that houses have become more air tight in recent decades, in part as an energy saving measure. At the same time the prevalence of exhaust fans has increased. Either of these factors would contribute to the possibility of adverse flow and this is even more so when they are in combination.

It was decided to commission an investigation of the conditions under which adverse flow with a flued heater can occur. This included examining the effects of exhaust fans and ventilation in depressurising the space in which the appliance was operating and the concentrations of carbon monoxide produced under various conditions. The experimental work of this investigation was carried out by the Australian Gas Association at its laboratory in Braeside, Victoria. The results of this work form part of this report.

The issues relating to this problem are complex. It is noted that the standard ASTM E1998-02 (2007) “Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances” considers adverse flow of the type noted above. It is significant that, while presenting various methods, it is mentioned in the ASTM standard that “*Although a number of different methods have been used to assess backdrafting and spillage .... a single well-accepted method is not yet availabl*e.”

2 BACKGROUND

2.1 Products of Combustion

The process of burning natural (NG) or liquefied petroleum (LP) gas creates a range of combustion products the major ones being carbon dioxide and water vapour. The combustion process also removes oxygen from the air and may produce harmful products, mostly in minor quantities, some of which are considered below.

2.1.1 Carbon Monoxide

Carbon monoxide (CO) is produced to some extent in virtually all instances where carbon containing fuel is burnt. Where the combustion is “good” (sufficient aeration and in the absence of flame impingement or other abnormality) the levels are very low. However, where “poor” combustion occurs (for example due to the factors described above) relatively high concentrations of CO can occur. CO is poisonous and, in its pure state, odourless. When produced by “poor” combustion, however, it usually occurs with formaldehyde and other compounds that have a strong odour; hence the smell of “poor” combustion.

The “National standards for criteria air pollutants in Australia” [1] sets an upper limit of 9.0 ppm (parts per million) for carbon monoxide “measured over an eight hour period” for ambient air. The USEPA National Ambient Air Quality Standards (NAAQS) [2] set the same (9 ppm) standard for an 8 hour averaging period but also include a one hourly average standard of 35 ppm. At high concentrations CO is highly toxic, as may be seen from the site quoted in reference 2 (http://www.lni.wa.gov/Safety/Topics/AtoZ/CarbonMonoxide/).

Other examples of health-based standards and guidelines relevant to unflued gas heater emissions may be found in reference 3.

2.1.2 Nitrogen Oxides and Other Pollutants

Nitrogen oxides (NOx) are produced as minor combustion products. They consist essentially of nitric oxide (NO) and nitrogen dioxide (NO_2). In most combustion processes NO is dominant, typically comprising about 95% of the NOx from large scale combustors. In cooler burning processes or where there is unburnt fuel or CO present in the products NO_2 may make up most of the NOx.

Of the NOx gases (NO and NO_2) NO_2 is the more toxic and the “National standards for criteria air pollutants in Australia” [1] sets upper limits in ambient air for it (NO_2) as 0.03 ppm averaged over a one year period and 0.12 ppm averaged over a one hour period. The USEPA sets 0.053 ppm as the annual arithmetic average and 0.100 ppm for the hourly average. Other health related guidelines are given in reference 3. Concentration limits for NO in ambient air have not been set.

Formaldehyde is an intermediate in methane combustion and can be released in the products under certain conditions. Other pollutants including particulate matter can also be present at very low levels.

2.1.3 Carbon Dioxide and Water Vapour

These are the products of complete combustion and within a suitable range are not harmful to health, in fact they are required. However at excessively high levels water vapour causes microbial or fungal growth and it is reported [3] that Health Canada has limited CO_2 levels in indoor air to 3500 ppm, a level that may be caused and exceeded by gas appliance usage in some circumstances.

2.2 Gas Appliances

Gas appliances may be situated indoors or outdoors. Indoor appliances may be classified flued (such as a water heater) or unflued (for instance, a flueless space heater). The indoor flued category is further subdivided between those fitted with a conventional flue and appliances with a balanced flue. Conventionally flued appliances may be natural draught or forced or induced draught. With natural draught appliances the buoyancy of the hot combustion products is relied upon to extract the combustion products, while forced or induced draught appliances incorporate fans for this purpose. The main focus in this part of the strategy document is on conventionally flued natural draught appliances and, in particular, the effect of operating an exhaust fan (or fans) on the flueing of such appliances.

The flue of a conventionally flued appliance is designed to discharge the products of combustion from the appliance to the outside atmosphere. However there may be situations created by external weather conditions or other factors, such as exhaust fans (the subject of this report), where atmospheric pressure indoors falls sufficiently below that outdoors that the natural draught is overcome leading to a reversal of the normal flow; outside air enters through the flue. This is termed adverse flow, down draught or backdrafting in US literature.

In order to cope with adverse flow (down draught), appliances must be fitted with a device that is intended to prevent the flue gases flowing down the flue from entering the combustion chamber as this could be expected to give rise to flame abnormality and the likely production of carbon monoxide, which would be vented into the indoor environment. The device commonly used to prevent this scenario is a (down) draught diverter. Draught diverters may be external to the appliance or integral, the latter being more common with modern appliances. The function of a draught diverter is to direct the adverse flowing gases away from the primary flue and prevent disturbance of the appliance's combustion processes. It may be noted that even with a correctly functioning draught diverter combustion products will enter the indoor environment during a period of adverse flow. It should, nevertheless, prevent flame abnormality and excessive carbon monoxide generation, although literature considered subsequently herein indicates that draught diverters are not always effective in this regard. Draught diverters also limit the updraught applied to the combustion chamber during periods of normal flue operation.

As above, a draught diverter is not intended to prevent the discharge of combustion products into the indoor environment. It follows that periods of adverse flow should be of limited duration only, as the appliance effectively operates as if it were unflued during such conditions. Furthermore, if an appliance is not operating satisfactorily and is producing high levels of CO and/or other pollutants in its combustion products these will be vented indoors.

A further situation where adverse flow can occur is when a pre-existing negative pressure exists, due to the operation of an exhaust fan (or fans) prior to starting a gas appliance. This may prevent the establishment of a flue draught for an unduly long period or at all. That is, the pre-existing low pressure created indoors and the associated inflow of air down the flue may prevent the development of normal flow (inside to outside) in the flue.

The potential for negative pressures to interfere with the proper operation of a conventionally flued appliance is recognised in the gas installation standard AS/NZS 5601.1:2010 "Gas installations". Clause 2.6.5 states, in part: *Negative air pressures shall be avoided except for industrial appliances and gas turbines specifically designed for negative air pressure.* Similarly Clause 6.3.1 rules out air pressures less than atmospheric at the gas appliance. A literal interpretation of these clauses would appear to prevent the installation of an exhaust fan or any other device or mechanism that could create a pressure deficit in a room or space that also had installed (or communicated with a space that had installed) a conventionally flued natural draught appliance.

AS/NZS 5601.1:2010 also sets requirements relating to the air requirements for conventionally flued appliances. Clause 6.4.4.1 states, in part: *Where the total input of the appliance(s) exceeds 3 MJ/h for each cubic metre (approximately 800 W/m^3) of the room or enclosure volume, the space shall be ventilated ...*, the corollary of this is that appliances with heat input rates of less than 3 MJ/(m^3.h) require only adventitious ventilation. It is, however, acknowledged in Note 2 of Clause 6.4.4.1 that adventitious ventilation may be inadequate in some modern well-sealed buildings.

It may be noted that balanced flue appliances are room sealed and draw their combustion air from a point in close proximity to where the combustion products are discharged (ensuring minimum atmospheric pressure difference between these points). Balanced flue appliances are not the subject of this report and are not considered further, except as a point of comparison with conventional flueing.

As noted above, many factors can contribute to the occurrence of adverse flow (or the failure to establish normal flow), these include:-

- *The type and design of the appliance or appliances (flue gas flow rate, temperature, efficiency, heat losses)*
- *The installation and flueing (flue height, diameter, fittings, geometry, termination)*
- *Building geometry and topology of surrounding area*
- *Wind effects (velocity and direction)*
- *Level of ventilation (number, size and placement of vents, adventitious ventilation)*
- *Use of exhaust fans (number, capacity, effect on area where appliances(s) is located)*
- *Presence of passive exhausting capacity (open fireplace and chimney, for instance)*

2.3 Exhaust Fans

The purpose of ventilation is to remove indoor air containing undesirable odours and/or pollutants and replace it with fresh outdoor air. In addition ventilation is also used in bathrooms to remove excess moisture.

In Australia and other parts of the world exhaust fans are extensively used to provide ventilation. There are other various configurations including:

- Push only, provides positive pressure ventilation with registers in areas where ventilation is mostly required. This applies a positive pressure inside the building and is fully compatible with conventionally flued natural draught gas appliances. A drawback is that during some seasons the air supplied may need to be either heated or cooled. This design is often used in commercial premises where there is a requirement to control the air quality.
- Push-pull provides mostly balanced pressure and when using conventionally flued natural draught gas appliances the argument could be mounted that the exhaust fans should be (slightly) smaller than the supply fans. Push-pull systems overcome to some extend the need to condition the air.
- Pull only, causes negative pressure ventilation and in combination with multiple fans and well sealed buildings is potentially not compatible with conventionally flued natural draught appliances because of the risk of adverse flow, depending on the level of negative pressure a given system generates. This is the most common type in domestic installations.

“Pull only” exhaust fan(s) necessarily create a negative pressure in the dwelling. If this negative pressure is sufficiently large it can overcome the natural draught of an operating conventionally flued natural draught appliance and thereby create the condition of adverse flow. Similarly, if the operation of the exhaust fan(s) preceded that of the gas appliance a pre-existing adverse flow in the flue could be expected. This may preclude or unduly delay the establishment of normal flow in the flue.

As all exhaust (pull only) fans create negative pressure and a major objective of this work was to establish the magnitude of negative pressure that is likely to interfere with the starting and operation of conventionally flued natural draught appliances. As noted in Section 2.2 above, the potential for negative pressures to interfere with the proper operation of this type of appliance is recognised in the gas installation standard AS/NZS 5601.1:2010.

The capacity and flow characteristics of the installed fan(s) and the level of ventilation available to the space in which the fan(s) is operating are major determinants of the likely negative pressure developed and hence the propensity to affect proper flue operation of a gas appliance. The question of ventilation is considered further in Section 2.5 below.

It was noted in the United States [4] some 20 years ago that tight houses and more powerful exhaust fans were resulting in increased instances of backdrafting [4] (adverse flow). The author observed: *The issue that should be addressed is not whether appliances have sufficient combustion air, but whether a house has sufficient make- up air to prevent backdrafting.*

In contrast another US report [5] centring on residences in Omaha found that *Cases of spillage that were detected were relatively rare and brief, indicating only minor, transitional spillage at appliance start-up. Most of these cases occurred from water heaters during periods of warmer weather, and the indoor air quality consequences were correspondingly minor.*

However, a further report [6] warns of the possibility of adverse flow and suggest *To minimize the potential for backdrafting the standard requires that naturally aspirated combustion appliances in the conditioned space have a spill switch, or pass a specific backdrafting test if the total of the largest two exhaust appliances exceed about 1 air change per hour of ventilation (not counting any summer cooling fans)*.

Following from Section 2.2 above, the gas installation standard AS/NZS 5601.1:2010, if interpreted literally, would rule out the installation of an exhaust fan(s) in a room that also had (or communicated with) a conventionally flued natural draught appliance when inside a modern tightly sealed residence. This is because for any exhaust fan to be effective it must create, in the indoor environment where it operates, a reduced indoor air pressure with respect to the local outdoor air pressure. It is noted that Energy Safe Victoria in Information Sheet No 28 [7] specifies a method of testing the effectiveness of a flued appliance with an exhaust fan operating, which would appear to implicitly accept the existence of a (slight) negative pressure Similarly, the US National Fuel Gas Code NFPA 54, 2006, (ANSI Z223.1–2006), Annex H, provides a method for the testing of adverse flow that involves operating exhaust fans at maximum speed (and so creating a negative pressure in the space where the appliance(s) is operating. It is reported that such configurations (exhaust fans operating in areas that communicate with conventionally flued natural draught appliances) are banned in France [8].

The level of ventilation required with appliance installation has major implications for the development of adverse flow and negative pressures. As seen in Section 2.2 the installation of a conventionally flued appliance with heat input rate of less than 3 MJ/(m^3.h) is allowed under AS/NZS 5601.1:2010, Clause 6.4.4.1 with reliance on adventitious ventilation only. The standard also notes that this may be inadequate in some modern well-sealed buildings. It seems apparent that in such circumstances (well-sealed buildings) the operation of an exhaust fan(s) would be likely to create a significantly large negative pressure and/or adverse flow. It is also significant that, with natural gas, a heat release intensity of 3 MJ/(m^3.h) within an enclosed space requires an air exchange rate of some 0.75 air changes per hour (ACH) within that space for complete combustion. When allowances are made for other air usages (including burner excess air and draught diverter dilution air, as specified in Appendix H of AS/NZS 5601.1:2010,) it is apparent that reliance on adventitious ventilation would be impractical in a tight house.

According to reference 9 *Indoor pressure as low as –3 Pascals can cause backdrafting*, the result of which can include .....*carbon monoxide and other combustion gases into a home and may cause flame roll-out.*. However, Richardson [10] warns of the need to ... *ensure that the suction in the room containing the appliance does not exceed 1 Pascal and cause draught diverter spillage*.. The Minnesota Energy Code sets a depressurisation limit of 5 Pa for atmospherically vented furnaces or boilers and decorative wood-burning appliance and 2 Pa for atmospherically vented water heaters [11, 12]. It is, of course, the case that temperatures in Minnesota can be much lower than in the areas relevant to this report.

The Health and Safety Executive (HSE) in the United Kingdom have commissioned a number of reports dealing with factors that may affect the flue performance of gas burning appliances [13-19]. Concerning the use of mechanical extraction (exhaust) fans, they concluded after major experimental investigations [17] that a pressure reduction of 3 Pa caused the flue to show a greatly enhanced propensity for flow reversal. Even a reduction of 1.8 Pa caused an increase in the tendency for reversal to occur in some conditions. Furthermore, the HSE tests referred to [17] were in two storey test houses with flues of some eight metres in height, which could be expected to generate a correspondingly higher draught than the much shorter flues that would be found in single storey dwellings. The work reported in reference 17 used test boilers of 8.79 kW (31.6 MJ/h) capacity with the minimum ventilation required (for a boiler of this size) of 17.95 cm^2 (1795 mm^2), as cited under BS 5440 Part 2.

The HSE investigations included a large number of tests into the effect on CO production of adverse flow as well as the area of ventilation necessary to overcome such adverse flow, which was generated by an exhaust fans(s). These tests ("Joint Industry Programme on carbon monoxide issues", Phases 1 and 2 [18, 19]) showed that very high (and poisonous) levels of CO entered the test room in several instances. In one case the CO concentration exceeded the analyser's scale, which went to 10,500 ppm (1.05% by volume). CO concentrations in this order are reported [2] to cause *Nearly instant death* to healthy adults.

The high CO levels noted immediately above were attributed to the adverse flows interfering with the appliances' combustion processes, despite the presence of draught diverters. Concerning the ventilator area necessary to overcome the potential effects of an exhaust fan(s), in producing adverse flow, the reports' authors concluded that the then current applicable standard (BS 5440-2: 2000 (Specification for the installation and maintenance of ventilation for gas appliances) was inadequate. Their recommendations are included as Appendix E of the present report.

Warren and Webb [20] conducted a mathematical analysis of the flue behaviour of domestic appliances that showed that: *The presence of even a small domestic extract fan may give rise to spillage of combustion products from an open-flued appliance*. They also reported that fan operation (as with some conditions of wind) can give rise two possible modes of flue operation, one of which would result in considerable spillage.

It is notable at Clause 5.8.3 of AS 1668.2. Part 2 - 2002 "The use of ventilation and air-conditioning in buildings" limits the pressure differential between compartments to 12 Pa, although this standard is strictly applicable to commercial rather than domestic applications.

It may also be noted that passive extraction (whether intentional or not) can produce significant negative pressures in the interior spaces of a dwelling [10, 17]. An open fireplace and chimney is an example of such a device, even though this may not be recognised [10].

A number of fan curves for commercially available units that are suitable for use as domestic exhaust fans are given in Appendix D. It can be seen that the capacity of some of these fans is sufficient to create a powerful adverse flow in the flue of a conventionally flued natural draught gas appliance which was installed in a room with limited ventilation. In such circumstances it is probable that normal flow in the flue would not establish or would be reversed if it had established before the fan was turned on.

Australian standard AS 4553-2008 specifies a velocity head of 7.5 Pa in testing the effectiveness of down draught diverters of natural draught appliances. It is apparent that, with a powerful exhaust fan and restricted ventilation (tight residence), down draughts in excess of 7.5 Pa could develop.

As seen in Section 1, the standard ASTM E1998-02 (2007) "Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances" deals with the question of adverse flow of the type above and notes that, while presenting various methods a well-accepted method is not yet available

2.4 Wind Effects

Wind can produce either internal pressurisation or depressurisation, depending on numerous factors including its velocity, direction and building geometry, orientation and the topology of the surrounding area. As above, the HSE has commissioned several extensive studies on wind and related effects [13-19]. In essence, as with exhaust fans, adverse conditions may arise under certain wind conditions that lead to flue flow reversal or oppose the establishment of normal flow.

Warren and Web [20] conclude that, as with exhaust fans, wind effects can lead to "bimodal" flue operation and in one of these modes (the low flow mode) there will be substantial spillage of combustion products from the draught diverter.

The pressurisation and depressurisation effects of wind might reasonably be expected to be intermittent, whereas, in contrast, an exhaust fan may operate on a semi-continuous basis. Reference 17 describes the interaction between wind and depressurisation effects and shows cases where wind induced pressure fields in the proximity of the flue termination can lead to flow reversal or the re-establishment of normal flow following a reversal.

2.5 Residential House Design

As an energy saving measure, both in Australia and elsewhere, there has been a tendency in recent decades to build houses that are more air tight [2, 21, and 22]. While this has contributed to reducing the heating load it has also resulted in decreased ventilation. Numerous studies have been conducted on ventilation rates in Australia and have shown a wide variation. For instance, Ferrari *et al* [23] reported the ventilation rates, in terms of air changes per hour (ACH) shown in Table 1 below:

Table 1

Air Change Rates Reported in Reference 23

City	Average	Maximum	Minimum
Sydney	1.1	3.8	0.12
Canberra	0.91	2.8	0.26
Victoria	1.2	3.4	0.18

Blogg [24] in a review of published air exchange rates conducted in September 2000 reported generally similar values to those shown in Table 1.

From the above, it follows that the operation of an exhaust fan(s) in relatively air tight dwelling or part thereof can be expected to produce a greater negative pressure than would otherwise be the case.

It is also the case that houses of recent construction tend to have multiple bathrooms and toilets, which creates the situation where many exhaust fans may be installed in a single dwelling. It is anticipated that in future such openings will be equipped with dampers, thus increasing the potential for a negative pressure to occur.

Reference 3 cites the Australian Building Code and Australian Standards (AS 1668.2 1991 and AS 3666). The code is quoted as requiring all occupied rooms to have *adequate flow-through or cross-ventilation and air quality*. This must be provided by natural ventilation from permanent, openable windows, doors or other devices with a combined openable size of not less than 5% of the floor area of the room to be ventilated, or a mechanical ventilation system conforming to the appropriate Australian standards (AS 1668.2 1991 and AS 3666).

2.6 Submissions

Three submissions were received from: an industry group, a concerned member of the public and a vendor of CO alarms.

These submissions did not provide any further information than GTRC already had under consideration, consequently the submission of the industry group was the only one with relevance.

The industry group request participation in the decision making process.

3 ACRONYMS AND DEFINITIONS

ACH	Air changes per hour
Adverse flow	Flow in the flue from the exterior to the interior of a building (usually downwards)
AS	Australian Standard
AS / NZS	Australian New Zealand Standard
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	ASTM International (formerly American Society for Testing and Materials)
Backdrafting	A US term for adverse flow
BCA	Building Code of Australia
Conventionally flued natural draught appliance	A combustion appliance that draws its air from its immediate surroundings and (under normal flow conditions) discharges the products to the outside via the flue. Also termed natural draught open flued appliance, or abbreviated to open flued appliance
CO alarm	A device that alerts by way of an audible sound when the level of carbon monoxide in the atmosphere where it is located exceeds a predetermined value for a specified period
CO sensor	An electrochemical cell or other transducer that responds to CO and produces an electrical signal that is transmitted to and interpreted by logic circuits in a CO alarm or other device
Draught Diverter	A device that is intended to isolate the combustion chamber of an appliance from the effects of pressure changes in the secondary flue. Also termed a down draught diverter and in US literature a draft hood. Described in Appendix A
Exhaust fan	A fan that moves air from the interior to the exterior of a building (also known as an extract or an extraction fan)
GF	Gas Fitter
HSE	Health and Safety Executive of the United Kingdom
Metastable	Is a state of equilibrium (not changing with time) that is susceptible to fall into lower-energy states with only slight interaction needed.
Natural draught appliance	See “conventionally flued natural draught appliance”
Natural draught	See “conventionally flued natural draught appliance”

conventionally flued appliance	
NCC	National Construction Code
Negative pressure	The state where the air pressure inside a building or enclosable section is such that air from the exterior tends to enter the building or space. Also termed sub-atmospheric pressure and pressure deficit
NFPA	National Fire Protection Association
Normal flow	Flow in the flue from the interior to the exterior of a building (usually upwards)
ODS	Oxygen depletion sensor
Open flued appliance	See “Natural draught conventionally flued appliance”
Pa	Pascal unit of pressure (1 N/m^2)
ppm	Parts per million (by volume in the context of the present report)
Primary flue	That part of an appliance’s flue from the combustion chamber to the draught diverter
Secondary flue	That part of an appliance’s flue from the draught diverter to the termination
Vitiation	Condition of combustion air whereby the oxygen contents is such that the performance of the burner could or has become sub-optimal.

4 TEST RESULTS

The AGA's laboratory in Braeside (Melbourne) was commissioned by Energy*Safety* WA to carry out tests using a flued space heater (wall furnace) to establish the level of negative pressure necessary to:-

- Effect a flue reversal with the appliance operating; and
- Prevent the establishment of normal flow against a pre-existing negative pressure

The tests, which are fully described in the AGA report which is included in Appendix B, were carried out with a wall furnace in a room that was sealed except for a variable inlet vent area. The experimental arrangement allowed for variation of fan speed and ventilation area.

It may be seen that the results of these tests are largely in conformity with the pressures indicated in the literature cited in Section 2.3 above; the level of negative pressure required to effect a flow reversal when the heater was operating was typically less than 4 Pa and as low as 2 Pa in one case. The negative pressure required to prevent normal flow establishment was, as might be anticipated, even lower at between 2 and 1 Pa

5 ASSOCIATED RISK

5.1 Consequence

Spillage of flue products into the house due to transient events, such as appliance start up or wind driven down draughts are unlikely to be significant.

Adverse flue flow due to exhaust fan operation may expose residents to the products of combustion for an extended period of time. Exposure to the chronic toxic products (CO, NO, NO_2) over a period of time may pose health effects.

If the flue adverse flow occurs simultaneously with the gas appliance producing high levels of CO, the possible consequences are acute and include serious illness and possible loss of life. It is also possible that, despite the presence of a draught diverter, an adverse flow may interfere with the combustion processes and cause the release of high levels of CO [18].

The inhalation of CO contaminated air has the potential to affect all members of the exposed population with the very young, elderly, pregnant and unwell being most vulnerable.

5.2 Carbon Monoxide Related Fatalities

Across Australia in the last 10 years the following fatalities have been attributed to CO poisoning from the use of gas:

Table 2 – CO Fatalities per Australian State/Territory over the Last 10 years

State / Territory	Fatalities	Fatalities per year per million head of population
Victoria	4	0.075
South Australia	4	0.250
Queensland	2	0.047
Western Australia	0	0.000
Tasmania	0	0.000
ACT	0	0.000
Total	**10**	**0.071**

At the time of publication, the data for New South Wales and the Northern Territory was not available.

According to the HSE [25], in the United Kingdom *Every year about 14 people die from carbon monoxide poisoning caused by gas appliances and flues which have not been properly installed or maintained.* Many others also suffer ill health. Other sources [26] put the figure substantially higher and it is reported [8] that *Over 300 people die in France each year as a result of incidents relating to gas installations, mainly due to carbon monoxide poisoning.*

5.3 Probability

The causal effect tree below shows the factors that contribute to a build-up of CO in living spaces from the operation of a gas appliance.

When taking the control measures into account several items become apparent.

1. The design and installation of the gas appliances is regulated and well controlled. There is a low probability of the design or installation causing a fatality.
2. The build-up over time of lint and dust in the appliance can affect the air flow and consequently increase the production of CO. Mechanical damage to the exterior of the appliance may cause an impingement of the flame on relatively cold surfaces which will produce high levels of CO.

   Local safety regulators recommend the periodically servicing of gas appliances, though this is not an enforceable requirement.

   Consequently there is a midrange probability that an appliance has not been serviced and produces high levels of CO.
3. The lack of controls in place to mitigate adverse flow due to the development of negative pressures. Given the increase in building tightness and the lack of awareness by the parties installing exhaust fans has given rise to a greater likelihood of this problem occurring.
4. Modern and renovated residences generally have more bathrooms and consequently have more exhaust fans than older 3 bedroom, 1 bathroom houses.
5. Flues are not regularly inspected and may suffer from blockages over time.
6. In areas with colder climates (Tasmania, New Zealand, Victoria, ACT) gas appliances operate for prolonged periods, possibly with intentionally limited ventilation.
7. The effect of combustion generated indoor pollutants on the individual will vary. Consideration needs to be taken that the occupants include the elderly, infants, frail, sick and pregnant.
8. The physiological effect of CO is highly time dependent and limiting the running time of exhaust fans (and hence negative pressure events) may be advantageous.

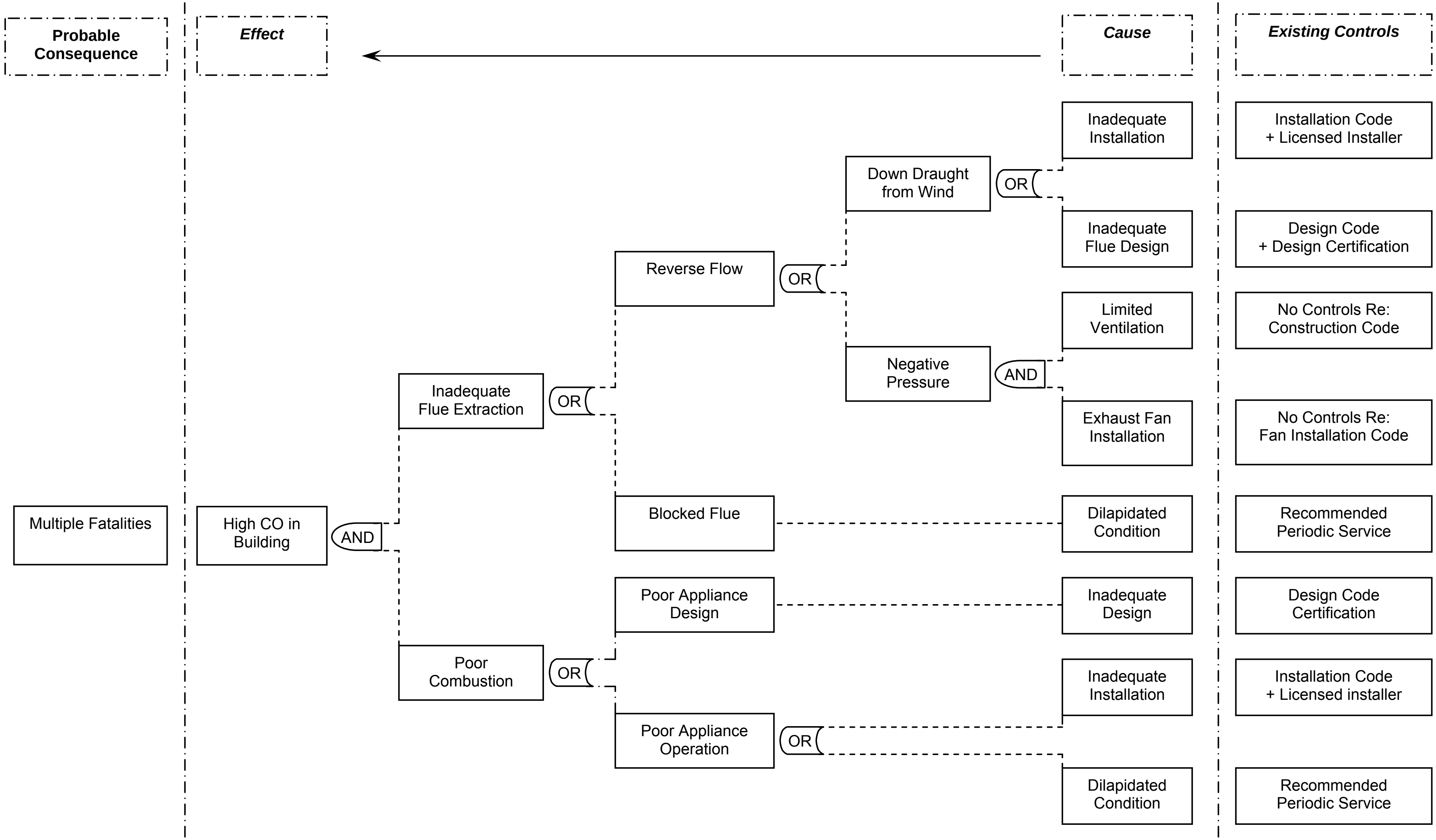

Figure 1 – Causal Effect Tree

6 EXISTING CONTROLS

Referring to the diagram on the previous page the existing controls shown in the right hand column are described in further detail.

6.1 Design Code Certification (Appliance Certification)

In Australia all gas appliances require certification to confirm that they meet the requirements of the relevant Australian Standard. The certification process involves a detailed analysis of the appliance and testing of its operation.

The relevant standard for residential space heaters is AS 4553-2008 "Gas space heating appliances". This standard includes the following relating to products of combustion and flue operation.

6.1.1 Operation Under Normal Conditions

Under the requirements of AS 4553-2008, flued heaters, unlike unflued (or flueless) heaters, are not required to be tested for the CO/CO_2 ratio of the combustion gases in normal operation. They are tested under a range of sub-optimal conditions (including overload) and the maximum CO/CO_2 ratio allowed is 0.02. The maximum CO/CO_2 ratio allowed for unflued space heaters is 0.002 when operating under normal conditions.

However, the operation of an unflued heater cannot be appreciably influenced by the creation of slight negative pressures as might occur with the use of exhaust fan(s) and consequently they are not relevant to the work reported here.

AS 4553-2008 Section 4.3 States

> *The CO/CO_2 ratio of the combustion products of any independent burner of an appliance operating at the test conditions specified below, shall not exceed—*
>
> *(a) 0.007 after 5 min for an indoor flueless appliance; or*
>
> *(b) 0.02 after 10 min for any other type of appliance.*
>
> *Burners intended for luminous effect and with adjustable aeration setting shall be tested at the minimum aeration setting.*

AS 4553-2008 Section 5.2.2 States

> *There shall be no leakage or spillage of combustion products from an open flued appliance, its flue system, or draught diverter, 5 min after ignition when the appliance is operated at nominal gas consumption.*

6.1.2 Operation Under Negative Pressure

For in-built gas appliances there are design requirements to avoid reaching dangerous CO production when appliances are exposed to a negative pressure. The values of 25 Pa and 250 L/s could be considered typical of an exhaust fan.

AS 4553-2008 Section 4.16 States

> *Appliances which are intended to be built into cavities in walls or partitions, cupboard recesses, or areas that communicate with other rooms or spaces, shall not exhibit flame abnormality and the CO/CO_2 ratio of the combustion products shall not exceed 0.02 when the cavity is subjected to any pressure between 25 Pa positive and 25 Pa negative providing the air flow required to produce such pressures does not exceed 250 L/sec.*

6.1.3 Operation Under Adverse Draught

The design of a flued gas appliance needs to be such that when operating under a down draught or high wind conditions, the appliance does not create dangerous levels of CO.

AS 4553-2008 Section 5.2.4.1 States

For all appliances with natural draught, open flued combustion systems equipped with a draught diverter or alternative system, the CO/CO_2 ratio shall not exceed 0.02 when operated with:

(a) The flue terminal of the appliance blocked.

(b) A downdraught having a velocity head of up to 7.5 Pa applied progressively to the flue terminal for one minute.

(c) An updraught having a velocity head of up to 7.5 Pa applied progressively to the flue terminal for one minute.

Note: A velocity head of 7.5 Pa is equivalent to an air flow velocity of 3.5 m/s. During testing the appliance is operated at nominal hourly gas consumption and in the case of appliances with turndown or modulating controls, the appliance shall be tested down to the lowest setting and sufficient intermediate points which characterise the appliance performance.

AS 4553-2008 Section 5.11.8 States

When winds irrespective of direction, are directed on to the flue terminal at speeds of 0 to 50 km/h, the appliance shall continue to function safely and the CO/CO_2 ratio of the combustion products shall not exceed—

(a) at not more than 10% of the possible wind angles, 0.03; and

(b) 0.02 at all other angles.

AS 4553-2008 Section 2.10.5 States

Where a flued appliance is fitted with a device to prevent the release of combustion products in a dangerous quantity into the room under abnormal draft conditions, the appliance shall:

(a) In the case of an appliance fitted with an atmosphere sensing device shut down before the air free CO concentration of the atmosphere in the test room exceeds 200 ppm by volume.

(b) In the case of an appliance fitted with a combustion products discharge safety device shut down within the times given in Table 2.5.

TABLE 2.5 SHUT DOWN TIMES

Degree of blockage	*Area of plate opening*	*Maximum shut down time (sec)*	
		On/Off	*Modulating*
Complete blockage	*0*	*200*	$200 \times Q_n/Q_m$
Partial blockage	*0.6A*	*600*	

where:

A is the internal area of the test flue at its top
Q_n is the nominal input of the appliance
Q_m is the input for appliances with modulation or turndown

(c) Nuisance shutdowns shall not occur.

(d) Where safety shutdown occurs, automatic restart shall only be possible after a minimum waiting time of 10 min. The manufacturer shall state in the instructions the actual waiting time.

6.2 Installation Code (Gas Appliance Installation)

Within Australia, built-in gas appliances are required to be installed and commissioned by a licensed gas fitter in accordance with the installation code AS/NZS 5601.1:2010 “Gas Installations” Part 1: General Installations

No State of Territory within Australia has mandated periodic service and maintenance of gas appliances. Most states actively promote periodic servicing at least every two years.

6.2.1 Operation Under Normal Conditions

The licensed gas fitter is required to install the appliance such that there is sufficient ventilation and the flue operates correctly.

Appendix H of AS/NZS 5601.1:2010 “Gas installations” also provides detailed design procedures for flue installations. The designs given are calculated to allow for approximately 50% burner excess air and approximately 100% draught diverter dilution air.

Energy Safe Victoria in Information Sheet No 28 [7] specifies a method of testing the effectiveness of a flued appliance with an exhaust fan operating.

AS/NZS5601.1:2010 Section 6.4.1 States

Gas appliances shall be installed in locations with adequate ventilation for complete combustion of gas, proper operation of the flue and to maintain the temperature of the immediate surroundings at safe limits, under normal operating conditions.

6.2.2 Operation Under Negative Pressure

As noted in Sections 2.2 and 2.3, the potential for negative pressures to interfere with appliance operation is recognised in AS/NZS 5601.1:2010. The specific clauses with the relevant text reproduced are shown immediately below:

AS/NZS 5601.1:2010 Section 2.6.5 States

Ventilation shall ensure proper operation of the gas appliance and flueing system and maintain safe ambient conditions.

Negative air pressures shall be avoided except for industrial appliances and gas turbines specifically designed for negative air pressure…

AS/NZS 5601.1:2010 Section 6.3.1 States

Gas appliances shall not be installed where the operation of any ventilation system, air distribution system, fan or air blower could, under any circumstances—

(a) deprive the gas appliance of the air required for combustion and draught diverter dilution;

(b) cause the air pressure to be less than atmospheric at the gas appliance; or

(c) otherwise adversely affect the operation of the gas appliance.

6.2.3 Operation under Adverse Draught

The gas appliance is required to be installed such that the likelihood of a flue downdraught is reduced. The standard considers wind as the most likely cause of downdraught.

AS/NZS 5601.1:2010 Section 6.9.1 States

> *The termination point of an open flue shall be located in relation to any associated building and to neighbouring structures so that wind from any direction is not likely to create a downdraught in the flue or chimney…*

6.2.4 Ventilation Requirements

As in Sections 2.2 and 2.3, AS/NZS 5601.1:2010 allows reliance on adventitious ventilation only for appliances with heat input rates of less than 3 MJ/(m^3.h). Note 2 of Clause 6.4.4.1 warns that adventitious ventilation may be inadequate in some modern well-sealed buildings.

AS/NZS 5601.1:2010 Section 6.4.4.1 States

> *Where an appliance(s), other than a room-sealed type, is to be installed in a room or enclosure, that room or enclosure shall be ventilated. Where the total input of the appliance(s) exceeds 3 MJ/h for each cubic metre (approximately 800 W/m^3) of the room or enclosure volume, the space shall be ventilated in accordance with Clauses 6.4.4.2, 6.4.4.3 and 6.4.4.4 in cases where natural ventilation is to be used, or Clause 6.4.4.5 in cases where mechanical ventilation is to be used, unless otherwise stated in Clauses 6.4.4.10 and 6.10. For the purpose of assessing the adequacy of ventilation, the space that cannot be isolated by doors is the 'volume of a room'.*

6.3 Construction Code (Residential House Design)

The National Construction Code (NCC Volume Two 2011) defines the design and construction requirements of residential premises and is mandatory.

From May 2011 new requirements on residential energy efficiency were published increasing house energy efficiency ratings from 5 to 6 Stars – adding further emphasis on the importance to improve controls to reduce the risks.

6.3.1 Ventilation Design to AS 1668.2-2002

When designing a mechanical exhaust system to AS 1668.2 consideration needs to be given to the supply of make-up air. Where drawn from outside, the pressure loss is not permitted to exceed 12 Pa.

AS 1668.2-2002 Section *5.8.1 States*

> *The air exhausted from enclosures shall be replenished by outdoor air or by make-up air of an acceptable quality from an adjacent enclosure. Make-up air shall not be drawn from an enclosure ventilated by a required exhaust system or from an adjacent car park. Make-up air from an enclosure ventilated by a required exhaust system may be acceptable for unoccupied enclosures, for example, make-up air from a car park for a garbage room exhaust system. Where desired, or where make-up air is not available, a supply-air ventilation system complying with Section 4 may be provided. Where the make-up air is drawn from outside the building, the intake shall comply with Clause 4.3.*
>
> *Make-up air from an enclosure served by a non-required exhaust system in conjunction with a mechanical supply or natural ventilation system is not prohibited.*

AS 1668.2-2002 Section *5.8.3 States*

> *Openings required in enclosure walls, ceilings or floors to allow passage of make-up air from adjacent enclosures or outside the building shall be of adequate size to ensure that the pressure drop between enclosures does not exceed 12 Pa.*

6.3.2 Ventilation for Indoor Air Quality

The NCC only requires exhaust fans installed in bathrooms and laundries to comply with acceptable construction practice. There is no reference to any potential hazards created by the installation of the fan (for instance where a conventionally flued gas appliance is situated or may be situated such that it is in communication with the fan(s)) or where the required makeup air is to come from.

NCC 2011 Volume Two P2.4.5 States

(a) A space within a building used by occupants must be provided with means of ventilation with outdoor air which will maintain adequate air quality.

(b) A mechanical air-handling system installed in a building must control—

(i) the circulation of objectionable odours; and

(ii) the accumulation of harmful contamination by micro-organisms, pathogens and toxins.

(c) Contaminated air must be disposed of in a manner which does not unduly create a nuisance or hazard to people in the building or other property.

NCC 2011 Volume Two 3.8.5.0 States

(a) Except for an exhaust fan from a sanitary compartment, laundry or bathroom, Performance Requirement P2.4.5 is satisfied for a mechanical ventilation system if it is installed in accordance with AS 1668.2 — Mechanical ventilation for acceptable indoor-air quality.

(b) An exhaust fan from a sanitary compartment, laundry or bathroom must comply with the acceptable construction practice.

NCC 2011 Volume Two 3.8.5.2 States

Ventilation must be provided to a habitable room, sanitary compartment, bathroom, shower room, laundry and any other room occupied by a person for any purpose by any of the following means:

(a) Permanent openings, windows, doors or other devices which can be opened—

(i) with an aggregate opening or openable size not less than 5% of the floor area of the room required to be ventilated; and

(ii) open to—

A. a suitably sized court, or space open to the sky; or

B. an open verandah, carport, or the like; or

C. an adjoining room in accordance with (b).

(b) Natural ventilation to a room may come through a window, opening, ventilating door or other device from an adjoining room (including an enclosed verandah) if—

(i) the room to be ventilated or the adjoining room is not a sanitary compartment; and

(ii) the window, opening, door or other device has a ventilating area of not less than 5% of the floor area of the room to be ventilated; and

(iii) the adjoining room has a window, opening, door or other device with a ventilating area of not less than 5% of the combined floor areas of both rooms; and

(iv) the ventilating areas specified may be reduced as appropriate if direct natural ventilation is provided from another source.

(c) *An exhaust fan or other means of mechanical ventilation may be used to ventilate a sanitary compartment, laundry or bathroom provided contaminated air exhausts—*

(i) *directly to outside the building by way of ducts; or*

(ii) *into a roof space that—*

A. *is adequately ventilated by open eaves, and/or roof vents; or*

B. *is covered by roof tiles without sarking or similar materials which would prevent venting through gaps between the tiles.*

6.3.3 Air Infiltration

For energy efficiency requirements the NCC requires a design to restrict the infiltration of outdoor air into the premises.

The reference to permanent ventilation openings for the safe operation of gas appliances relates to ventilation requirements in AS/NZS 5601

NCC 2011 Volume Two 3.12.3 States

(a) *This Part applies to—*

(i) *a Class 1 building; and*

(ii) *a Class 10a building with a conditioned space,*

(b) *excluding the following:*

(i) *A building in climate zones 1, 2, 3 and 5 where the only means of air-conditioning is by using an evaporative cooler.*

(ii) *A permanent building ventilation opening that is necessary for the safe operation of a gas appliance.*

(iii) *A Class 10a building used for the accommodation of vehicles.*

NCC 2011 Volume Two 3.12.3.3 States

(a) *A seal to restrict air infiltration must be fitted to each edge of an external door, openable window and other such opening—*

(i) *when serving a conditioned space; or*

(ii) *in climate zones 4, 5, 6, 7 and 8, when serving a habitable room.*

(b) *A window complying with the maximum air infiltration rates specified in AS 2047 need not comply with (a).*

(c) *A seal required by (a)—*

(i) *For the bottom edge of an external swing door, must be a draft protection device; and*

(ii) *For the other edges of an external swing door or the edges of an openable window or other such opening, may be a foam or rubber compressible strip, fibrous seal or the like.*

NCC 2011 Volume Two 3.12.3.4 States

An exhaust fan must be fitted with a sealing device such as a self-closing damper, filter or the like when serving—

(a) *a conditioned space; or*

(b) *a habitable room in climate zones 4, 5, 6, 7 and 8.*

NCC 2011 Volume 2 Section 3.12.3.5 States

(a) Roofs, external walls, external floors and any opening such as a window frame, door frame, roof light frame or the like must be constructed to minimise air leakage in accordance with (b) when forming part of the external fabric of—

(i) a conditioned space; or

(ii) a habitable room in climate zones 4, 5, 6, 7 and 8.

(b) Construction required by (a) must be—

(i) enclosed by internal lining systems that are close fitting at ceiling, wall and floor junctions; or

(ii) sealed by caulking, skirting, architraves, cornices or the like.

NCC 2011 Volume Two 3.12.3.6 States

An evaporative cooler must be fitted with a self-closing damper or the like when serving—

(a) a heated space; or a habitable room in climate zones 4, 5, 6, 7 or 8.

6.4 Gas Fitting Licence

In all Australian states and territories fitting work may only be performed by a licensed gas fitter. In order to obtain a gas fitting licence the applicant is required to have been assessed to a Certificate IV national competency.

6.5 Recommended Periodic Service

It is recommended that gas appliances should be serviced in accordance with the manufacturer’s instructions. Generally, a two year service period is considered good practice recommended by the technical regulator.

6.6 Electrical Installation Code (Exhaust Fan Installation)

6.6.1 Electrical Installation AS/NZS 3000:2000

Exhaust fans are required to be installed by licensed electricians. The electrical installation standard AS 3000 defines the requirements for the installation.

It is important to note that this installation standard does not recognise the creation of hazards resulting from the normal operation of an electrical appliance. Therefore electricians installing exhaust fans have not received training in relation to ventilation and its effect on gas appliances.

AS/NZS 3000:2000 Section 1.1 States

This Standard sets out requirements for the design, construction and verification of electrical installations, including the selection and installation of electrical equipment forming part of such electrical installations.

These requirements are intended to protect persons, livestock, and property from electric shock, fire and physical injury hazards that may arise from an electrical installation that is used with reasonable care and with due regard to the intended purpose of the electrical installation.

In addition, guidance is provided so that the electrical installation will function correctly for the purpose intended.

AS/NZS 3000:2000 Section 1.7.1 States

Electrical equipment, forming part of an electrical installation, shall be selected and installed to—

(a) operate in a safe and reliable manner in the course of normal operating conditions; and

(b) not cause a danger from electric shock, fire, high temperature or physical injury in the event of reasonably expected conditions of abnormal operation, overload, fault or external influences that may apply in the electrical installation; and

(c) be installed in accordance with the manufacturer's instructions.

7 POSSIBLE NEW CONTROLS

Different proposed control measures are discussed in detail below along with the perceived advantages and disadvantages.

A description is included with the detail of the control measure, as shown below:

1. Procedural or Physical: A physical control measure aims to mitigate the risk without any intervention from the occupants. A procedural control measure requires the occupants to react or perform a task in some way.
2. Reactive or Preventative: Preventative control measures mitigate the risk prior to the hazard occurring. Reactive control measures activate after the hazard has arisen.

Table 3 – Control Measure Matrix

	Preventative	Reactive
Physical	Preferred	Second Preference
Procedural	Second Preference	Non Preferred

7.1 Carbon Monoxide Alarms

The use of CO alarms is an approach that has found a degree of favour in recent years. While the use of these alarms might seem an obvious solution to the question of how inhabitants of a dwelling might be protected from hazardous levels of CO there are two salient points that be addressed:

1. The number that are required to afford high level protection and their reliability. The comment has been made that .... *no CO* alarm *is better than a faulty one*.
2. Depending on how and where the CO is produced, there may be very significant concentration gradients, with toxic levels at one location within a building and relatively low levels elsewhere in the same building.

This suggests that multiple alarms would be required in a normal domestic dwelling to assure coverage and identify any pockets of high CO concentration.

A very recent (reported 2011) study was carried out to assess the reliability of CO alarms by the HSE [32] and has concluded that newer models are superior and their lifetimes can now be expected to be from 5 to 7 years. The HSE study was unable to assess the reliability of alarms of greater than 2 years in age, however it was noted that *The reliability of the most common models of CO alarms available in the UK, particularly over their first four years of life, as judged by conformance to the British standard BS EN 50291 and the broadly equivalent US standard UL 2034, appear to have improved significantly since the last study of this kind in 2003.* Of the 110 CO alarms tested in this study nine failed the initial test and one failed a gas test. Of the initial nine failures six were a result of battery depletion.

An earlier United States report [33] found many makes of CO alarms to be unreliable, as may be seen in the following quotation taken from the report's abstract: *Alarms of six of ten commercially available brands behaved inconsistently, with one half of the devices failing to alarm in at least one test at dangerous CO levels and moderate humidity, and four out of five failing to alarm at low humidity. Three of seven commercially available brands with digital displays were accurate to within ±30%, with one brand being accurate to within ±10%. The other four brands were highly inaccurate with a significant portion of alarm units of two brands reading 0 ppm when exposed to CO concentrations as great as 100 ppm.* It was also pointed out that *Many UL-certified alarms continue to fail the basic sensitivity requirement of the UL standard.* and further that *The inaccuracy of several brands is so great as to indicate that the alarms do not meet their basic sensitivity specification, and will not alarm at dangerous CO* *levels.* In addition false alarming was observed as was alarming with interfering gases and very high failure rates at low humidity levels.

According to the HSE report [32], guidance based on BS EN 50292, recommends that alarms are fitted as follows:

- in every room that contains a fuel burning appliance,
- at least 300 mm from any wall (for ceiling mounted alarms),
- at least 150 mm from the ceiling, above the height of any door or window (for wall mounted alarms),
- between 1 and 3 m (measured horizontally) from the potential source of CO.

It is also noted in the report [32] to *Ensure that your CO alarm is correctly located – check the instructions from the manufacturer. Over 20% of alarms sampled were not fitted correctly, mainly due to being at the wrong height or not close enough to the potential source of CO*.

Some 30 years ago EnergySafety personnel (then employed by SECWA) observed at least one case where very high levels of CO were emitted by an unflued water heater, yet the CO concentration in the atmosphere in the vicinity of the appliance was low. However, lethally high levels were found in a bedroom some metres away: the CO laden air having been transported along a passage in a layer close to the ceiling. The type of appliance concerned was disallowed in Western Australia from the mid 1980's.

Despite the good reliability of modern CO alarms noted in their report [32], the HSE makes the point that *Audible carbon monoxide (CO) alarms are a useful back-up precaution, but they are not a substitute for the proper installation and maintenance of combustion heating appliances.*

An HSE report on the siting of CO alarms [34] considers in detail issues relevant to their positioning. In particular, it is reported that the optimal locations for the alarm sensors are Primary Room walls less than 0.8 m from ceiling and that changing the alarm siting from the optimal location to either of the adjacent rooms at the ceiling height or to Primary Room lower positions reduces alarm effectiveness by approximately 25-30% and increases the unpredictability of the alarm performance. Further, changing the alarm siting from the optimal location to rooms other than Primary roughly halved the alarm effectiveness and doubled the performance unpredictability. They also observed that, the sensitivity of alarm performance with height in the Primary Room can be strongly influenced by the characteristics of the appliance and the installation.

A 2009 Study on the "Provision of Carbon Monoxide Detectors Under The Building Regulations" commissioned by the (UK) Department for Communities and Local Government [35] concluded: *This report has shown that installing CO detectors alongside new gas appliances (already incorporating secondary safety systems) gives an extremely low cost benefit. However, in the instance of solid fuel (without secondary safety system) or boats or caravans, the use of CO detectors is clearly cost effective.*

Table 4 gives the test regime specified in ANSI/UL 2034-2005 for CO alarms.

Table 4 – Test Regime for CO Alarms

ANSI/UL 2034

CO Concentration (ppm)	Response Time (mins)
70 ± 5	60-240
150 ± 5	10-50
400 ± 10	4-15

BS EN 50291

CO Concentration (ppm)	Response Time (mins)
30	>120
50	60-90
100	10-40
300	<3

The recent (2011) HSE report [25] relating to gas safety recommends the following initiatives that should be considered in relation to CO:

- audible CO detection alarms, which can be very effective and reliable
- what more can realistically be done by the emergency gas services when attending at a possible CO poisoning situation
- phasing out of old and open flued appliances, especially boilers, which represent higher risk
- use of the home energy rating scheme to highlight hazards and safety measures connected with domestic gas
- promotion of clinical awareness of CO symptoms and detection, especially among GPs and pathologists

In Australia there are an estimated 4.2 million dwellings in which conventionally flued natural draught appliances are installed. The fitting of multiple CO alarms in each of these to the required level of workmanship will be a very large undertaking which seems untenable given the that the rate of accident and incidents occurring from flued appliances is believed to be small, with an average rate of fatalities below one per annum in recent years. Expenditure of such a large sum in mitigating accidents in other areas would undoubtedly lead to a superior outcome. As an example, a much smaller (by orders of magnitude) expenditure involving the installation of CO alarms in caravans could be expected to have a more positive outcome in protecting the public from CO poisoning.

A CO sensor that could operate in the flue stream and was linked to cut the gas supply would seem a more viable proposition. However, it is unlikely that low cost and reliable versions of the sensors capable of operating in this mode are currently available and, even if they are, retrofitting them to existing appliances would be a very large undertaking.

It is important that a clear distinction is drawn between the CO alarms and smoke alarms, the latter providing a warning of acute and present danger that demands immediate attention.

7.1.1 Control Measure Type

Table 5 – Control Measure Matrix- CO detection

	Preventative	Reactive
Physical		
Procedural		Non Preferred

7.1.2 Estimated Implementation Cost per Household

Initial capital cost:	\$300 to \$500 (Dependent on the number of CO alarms installed)
	+ \$300 for gas supply interruption (automatic shutoff valve)
Installation cost:	\$400 to \$500 (Licensed electrician required to hardwire power supply)
	+ \$200 for installation of automatic shutoff valve by licensed gasfitter
Ongoing cost:	\$150 (Average cost per year to cover replacement and testing of alarms)

In summary without interruption of gas supply \$700-\$1000 per dwelling and \$1200 to \$1500 with interruption to the gas supply.

At around 4.2 million the estimated cost would be around \$4B without interruption and \$6B with interruption. Then if maintenance and replacement is added in over a 10 year period the cost of this control will double.

7.1.3 Applicability to Existing Installations

CO alarms can be installed retrospectively to existing installations

7.1.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. Provide an additional safety measure
2. Will alarm on high CO concentration regardless of its origin
3. Can be linked into gas supply and cut off gas to all appliances on high CO reading, though this entails added cost and complexity.
4. Unlike inferential protection measures, which operate on factors that are or may be associated with CO production, CO alarms directly sense carbon monoxide.

Disadvantages

1. Is not a control measure unless the alarms interrupt the gas supply.
2. Alarm sensors are consumable and require periodic servicing and replacement
3. At least until recently alarms have suffered from a high level of unreliability, a faulty alarm indicating low levels of CO when high levels are present would be a major hazard
4. Multiple alarms are required to be effective and the positioning can be a critical issue
5. Unless the alarm is linked into the gas supply it provides only a warning rather than effecting corrective action by removing the CO source
6. As above, there are cost implications for linking an alarm sensor into the gas supply.
7. Spurious alarms may lead to complacency by residents such that they may ignore a true alarm.
8. There are currently no standards that cover the; manufacture, installation or servicing of CO alarms in Australia.
9. Installation of the required number of alarms to the level of sophistication needed to achieve the desired outcome would be the most expensive control measure for the lowest gain in safety.

7.2 Spill Switches

A spill or spillage switch is a device that is intended to sense the presence of spillage at the draught diverter (caused by adverse flow) and, through linkage to the gas supply, turn off the appliance. Spill switches are typically thermally activated devices [36] and are found on various types of gas appliances [36]. It is notable that in the early 1980's the US Consumer Product Safety Commission [37] cited a report which concluded that .. *thermal spill switches were the most suitable devices currently available to reduce the risk of CO poisoning from central heaters* The same report noted a greater incidence of CO poisoning from vented (flued) than unvented (unflued) heaters. The US National Fuel Gas Code NFPA 54, 2006, (ANSI Z223.1–2006) also cites the use of devices that ..*will automatically shut off gas to the burner in the event of sustained backdraft is recommended if such backdraft might adversely affect burner operation or if flue gas spillage might introduce a hazard*.

Although spill switches are not mandated under Australian standard AS 4553-2008 "Gas space heating appliances", as noted in Section 6.1.3 above, Clause 2.10.5 of the standard "Safety shutdown—combustion products limits" of requires that ....*Where a flued appliance is fitted with a device to prevent the release of combustion products in a dangerous quantity into the room under abnormal draft conditions, the appliance shall:*

(a) In the case of an appliance fitted with an atmosphere sensing device shut down before the air free CO concentration of the atmosphere in the test room exceeds 200 ppm by volume.

(b) In the case of an appliance fitted with a combustion products discharge safety device shut down within 200 seconds in the case of complete flue blockage (for an "on/off" appliance) and within 600 seconds where a blockage of 60% of the flue area occurs.

Spill switches are commercially available, permissible in the appliance design standard and, as above, are currently used on some appliances.

Spill switches may work well in a blocked flue situation, where the flue products pass undiluted from the primary flue and out through the draught diverter. However due to the dilution of the flue products under strong adverse flow conditions, the temperature rise of the products vented from the draught diverter (effectively the signal to noise ratio for the spill switch) is considerably lower and would depend on the specific installation, including appliance type, efficiency, flue, room size, ventilation and the exhaust fan(s) characteristics. Given the many parameters noted above, the temperature rise of gases exiting the draught diverter under adverse flow conditions can be highly variable. In some tests values in the order of 60 to 80^{0}C have been observed. However with powerful exhaust fans and minimal ventilation openings lower values are likely.

Spill switches do not directly sense CO and may not afford protection against high levels of CO generation, such as some cases cited in reference 18.

7.2.1 Control Measure Type

Table 6 – Control Measure Matrix- Spill Switches

	Preventative	**Reactive**
Physical		**Second Preference**
Procedural		

7.2.2 Estimated Implementation Cost per Household

Initial capital cost: <\$30 (additional cost to manufacture, increase in appliance cost)

Installation cost: Nil

Ongoing cost: Nil

7.2.3 Applicability to Existing Installations

Not practical to retrospectively install on existing gas appliances.

7.2.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. Spill switches are a low cost safety device that could be mandated on all conventionally flued natural draught appliances.
2. Spill switches are well proven devices and introducing a requirement for their incorporation on flued appliances would be viable.
3. Spill switches are inherently linked into the gas supply of the appliance and activate a fail-safe cut off of the gas if the flame is extinguished.
4. They are robust devices that should, with proper maintenance, last for the life of the appliance (though evidence of their long term performance has not been obtained).
5. Under a blocked flue situation the spill switch will operate
6. Low cost

Disadvantages

1. Although they are effective in a blocked flow situation they may not operate under conditions of adverse flow.
2. A spill switch may not provide protection against high levels of CO
3. May be impractical to retrofit into existing appliances

7.3 Ventilation design and installation

Currently in residential premises the effect of an exhaust fan(s) on the room air pressure is not considered. As dwellings become tighter (for instance with the implementation of 6 Star Rating buildings under the BCA) with improved energy efficiency requirements the potential for both the duration and intensity of negative pressure events will increase. The effect of this tightening in generating negative air pressures indoors is exacerbated by the installation of more powerful exhaust fans.

Design of exhaust systems that are not vulnerable to adverse flow situations is possible through increased ventilation openings (see below) and more sophisticated fan operation, possibly including “push-pull” operation or a pressurising fan only. The “push-pull” system adds complexity and expense and may not be suitable to be retrofitted in a significant proportion of existing installations. A pressurising fan is not expected to be as effective in expelling contaminated air as a simple exhaust (depressurising) fan. .

The commercial ventilation design standard AS1668.2-2002 includes consideration of make-up air for exhaust systems. When drawing from an adjacent room the standard limits the pressure loss to 12 Pa. As shown in the commissioned testing (Appendix B) and the literature sources consulted, a depressurisation of 12 Pa is more than sufficient to reverse the flow in the flue of a conventionally flued natural draught appliance.

Based on the test results (and the literature), in order to avoid reverse flow in the flue the exhaust system would need to be designed to ensure that room depressurisation does not exceed 1 to 2 Pa. The cost of such a program would be prohibitive and the logistics extremely difficult.

The inclusion of a ventilation opening in the exhausted area would decrease the negative pressure in the space. There is also the option to install actuated dampers on the ventilation opening such that they open when the fan is turned on. Due to the very low negative pressure required to reverse the flow in the flue these openings will need to be relatively large.

The effectiveness of increased vent area in overcoming flue reversals has been the subject of considerable investigation by the HSE and others [18-20, 38]. The UK Building Regulations Part J [39] limit the extract rate of a kitchen extract fan to 72 m^3/h and warn of the potential hazards of depressurisation. It also advises that a spillage test should be conducted when the appliances under test are subjected to the greatest possible depressurisation. Introducing requirements limiting the allowed level of negative pressure developed by an exhaust fan in an installation does not seem a viable option. The pressures are small and accurate measurements are difficult. Furthermore, in many instances exhaust fan are installed subsequent to gas appliances.

7.3.1 Control Measure Type

Table 7 – Control Measure Matrix-Ventilation

	Preventative	Reactive
Physical	**Preferred**	
Procedural		

7.3.2 Estimated Implementation Cost per Household

Initial capital cost: $100 to $200 (for additional fans or actuated ventilation openings)

Installation cost: $150 (Installed during construction phase, electrician on site)

Ongoing cost: Nil (slight increase in power use not considered significant)

7.3.3 Applicability to Existing Installations

Practically this would only be considered on new housing designs

7.3.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. Improving ventilation by the installation of “push-pull” fans or pressurisation ventilation could be expected to be an effective measure in virtually eliminating instances of adverse flue operation
2. Including an actuated ventilation opening would provide makeup air to the exhaust system and decrease the house negative pressure
3. The provision of make up air (push-pull or ventilation openings) would improve the effectiveness of the exhaust system.
4. Removes the cause of adverse flow of the flue products.

Disadvantages:

1. “Push-pull” fans add cost and complexity
2. Pressurisation fans may not be considered as effective as exhaust fans in removing contaminated air
3. Ventilation openings would need to be large and possibly actuated.
4. Difficult to implement on existing house designs
5. High levels of ventilation are inconsistent with efforts to reduce household energy consumption.

7.4 Oxygen Depletion Sensors

Oxygen depletion sensors [40] were originally developed in the 1960's and were first used with unflued LPG appliances. Since 1985 they have been a mandatory component of unflued space heaters approved under the AGA/AS schemes. An ODS typically consists of a metastable pilot flame which extinguishes (lifts off) if the CO_2 level in the combustion air exceeds a certain level (2% under the current version of AS 4553). It is, of course, the case that increased levels of CO_2 are associated with reduced O_2 concentrations. It has been proposed that ODS pilots could similarly be a requirement on conventionally flued natural draught appliances as a means of protection against excessively high levels of air vitiation. It follows that the protection afforded by ODS's against high concentrations is inferential only.

ODS pilots are always linked into the gas supply by a fail-safe mechanism that cuts off the gas when the pilot extinguishes. ODS's are mature technology in relation to unflued gas space heaters and it is envisaged that they could be incorporated into existing designs of open flued gas appliances, though this may require some adaptation and additional cost.

It may be appropriate to set the ODS cut out somewhat lower in the case of a flued appliance than for an unflued heater (which under AS 4553-2008 is 2%). For instance, if a heater was producing excessively high concentrations of CO (for example, if the CO/CO_2 ratio was 0.1), then 2% CO_2 in the heated space would correspond to 2000 ppm CO, which is potentially lethal. CO production rates exceeding even this high level have been reported under adverse flow conditions [18, 19].

The incorporation of ODS's in new open flued appliances is therefore supported. However retrofitting them into existing appliances on the scale required appears impractical. Further, incorporation of ODS pilots into flued appliances may present issues that differ from those which occur with unflued space heaters, where they are well established.

7.4.1 Control Measure Type

Table 8 – Control Measure Matrix-ODS

	Preventative	Reactive
Physical		Second Preference
Procedural		

7.4.2 Estimated Implementation Cost per Household

Initial capital cost: <$50 (additional cost to manufacture, increase in appliance cost)

Installation cost: Nil

Ongoing cost: Nil

7.4.3 Applicability to Existing Installations

Not practical to retrospectively install on existing gas appliances

7.4.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. ODS's now well proven devices and introducing a requirement for their incorporation on flued appliances would seem viable.

2. Unlike CO alarms, ODS pilots are inherently linked into the gas supply of the appliance and activate a fail-safe cut off of the gas if the flame is extinguished.

3. ODS's are robust devices that should, with proper maintenance, last for the life of the appliance (though evidence of their long term performance has not been obtained).

4. An ODS will respond to reduced oxygen levels in the space within which it is operating regardless of how the deficiency occurred.

5. Low cost

Disadvantages:

1. Impractical to retrofit into existing appliances

2. ODS's respond inferentially, rather than directly, to possible CO concentrations.

3. An ODS may not provide protection against harmful levels of CO in a case where an appliance was spilling combustion products containing an excessively high concentration of CO.

4. Not all gas appliances feature stand alone pilots with many electronic ignition systems. This would lead to significant adaptation costs.

7.5 Appliance Servicing

It is recommended that gas appliances should be serviced at intervals as specified by the manufacturer. This keeps them in good condition and minimises the likelihood of significant CO generation. An option is to mandate periodic maintenance of gas appliances in rental accommodation and further promote maintenance for owner occupiers. However maintenance of this kind will not prevent adverse flue flow due to negative pressures.

7.5.1 Control Measure Type

Table 9 – Control Measure Matrix mandated Maintenance of Appliances

	Preventative	Reactive
Physical		
Procedural	Second Preference	

7.5.2 Estimated Implementation Cost per Household

Initial capital cost: Nil

Installation cost: Nil

Ongoing cost: $200 every 2 years

7.5.3 Applicability to Existing Installations

Servicing can be performed on all gas appliances

7.5.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. Keeps appliances in good condition and unlikely to produce CO.
2. Assists in reducing exposure to other pollutants and the associated chronic effects
3. Periodic maintenance will find any other safety issues with the gas installation
4. Assists in efficient operation of the appliance

Disadvantages:

1. Is not a stand alone control measure because it does not address the issue of adverse flue operation.
2. Creates a periodic cost burden
3. Difficult to mandate to all properties, likely to be a requirement for rental properties only

7.6 Room Sealed Appliances (Appliance Type)

The removal of conventionally flued natural draught appliances from the market and their replacement with room sealed appliances would overcome the potential for CO exposure. These appliances draw the air for combustion from the outside, exhaust the products of combustion through a flue and are sealed from the interior of the house. Due to the sealing of the appliance they are not affected by the room pressure and can not exhaust into the living spaces.

However, under the current market they would be cost prohibitive and retrofitting them in place of existing natural draught appliances is impractical. If mandated on all new dwellings, market forces would likely provide a greater selection and reduce the capital cost over time.

There is also the potential to use forced draught appliances, which use a fan to mechanically force the products of combustion to the outside. These units are not sealed from the living space, but adverse flow under negative pressure would be extremely unlikely.

7.6.1 Control Measure Type

Table 10 – Control Measure Matrix-Appliance Type

	Preventative	Reactive
Physical	Preferred	
Procedural		

7.6.2 Estimated Implementation Cost per Household

Initial capital cost: $500 (Currently there is a limited number of suppliers, comparison against open flued appliances)

Installation cost: Nil (potential for savings with flue design)

Ongoing cost: Nil (potential for savings in service costs)

This will also likely impose cost implications on the appliance manufacturing and supply industry which will need to be taken into account.

7.6.3 Applicability to Existing Installations

Possible to replace existing open flued appliances, however this would be cost prohibitive

7.6.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. The use of room sealed appliances represents a stand alone control measure of the highest order, representing elimination of the hazard.
2. Removes the possibly of exposing occupants to toxic combustion gases except under the most unlikely fault conditions
3. Will also mitigate the long term chronic effects of exposure to the products of combustion.
4. Typically are higher efficiency appliances.

Disadvantages:

1. High capital cost
2. Currently there is a limited selection of room sealed heaters on the market
3. Impractical to replace existing stock of natural draught appliances with room sealed equivalents

7.7 Exhaust Fan timer

A possible measure to reduce the hazard of negative pressures created by exhaust fans is to retrofit timers that limit the operation to (say) 10 mins only after which the fan must be manually restarted. A further option would be to lock the fan out for a further (say) 5 minutes before a restart was possible. This option appears the most realistic in cost and logistics terms. The proposed times of operation (and possible outage) are suggestions only and further work would be required to determine if they are optimal.

7.7.1 Control Measure Type

Table 11 – Control Measure Matrix – Exhaust Fan Timer

	Preventative	Reactive
Physical	Preferred	
Procedural		

7.7.2 Estimated Implementation Cost per Household

Initial capital cost: $50

Installation cost: Nil for new construction, $200 existing (will require a licensed electrician)

Ongoing cost: Nil

7.7.3 Applicability to Existing Installations

Simple to retrospectively install.

7.7.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. Low cost
2. Easy installation
3. Improves house energy efficiency
4. Capable of retrofitting to existing premises

Disadvantages:

1. Limits the utility of the fan
2. May cause inconvenience to user in some circumstances
3. Cannot be considered a stand alone control measure, will need to implemented with additional controls

7.8 Public Awareness Campaign

An alternative approach to taking any of the above actions is to engage in a public awareness campaign advising of the potential hazards of allowing negative pressures to develop in areas where they could affect the operation of natural draught open flued appliances. The campaign would centre on the possible hazards created when an exhaust fan(s) is allowed to operate simultaneously with a conventionally flued natural draught appliance which is located in an area where the negative pressure created by the fan could affect the operation of the appliance. The campaign might also advise consumers on efforts to improve the energy efficiency of dwellings, but also point out that this can restrict the level of adventitious ventilation and make dwellings more susceptible to the hazards created by exhaust fans.

It is anticipated that such a campaign would advise that adequate ventilation (open doors and/or windows) must be provided during periods while exhaust fans are running or simply that exhaust fans and flued gas appliances must not be operated simultaneously. The campaign may include newspaper advertisements and bill inserts to gas customers. Such bill inserts may include stick-on labels recommended for placement near the fan switch and/or the gas appliance warning of the potential hazards. It may also note that the potential hazard extends to other types (than gas fuelled) of open flued combustion appliances.

7.8.1 Control Measure Type

Table 12 – Control Measure Matrix – Public Awareness Campaign

	Preventative	Reactive
Physical		
Procedural	Second Preference	

7.8.2 Estimated Implementation Cost per Household

Initial capital cost: Nil

Installation cost: Nil

Ongoing cost: Nil (will likely increase the uptake of servicing at $200 every 2 years)

There will be an ongoing cost implication to the responsible party to organise the campaigns.

7.8.3 Applicability to Existing Installations

Applicable to all installations

7.8.4 Summary of Appropriateness

A summary of the advantages and disadvantages of this control measure is shown below:

Advantages:

1. Low cost option
2. Avoids the necessity to carry out physical work in consumers' premises

Disadvantages:

1. Does not eliminate potential problems
2. Relies on awareness of consumers and their willingness to comply with recommendations
3. Needs to be implemented continuously over an extended period of time

8 CONCLUSIONS

The following conclusions are reached:

1. There has been an increasing tendency to make dwellings ever more air tight as an energy saving measure. This is reflected in the introduction of the highly thermally efficient 6 Star Rating for buildings. At the same time there has been a concurrent growth in the installation and power of exhaust fans. Unlike overseas standards, the National Construction Code does not appear to reflect the importance of correctly engineered ventilation systems when pursuing higher thermal efficiencies of buildings. This becomes a major contributing factor in the development of negative pressure in residential buildings.
2. Use of exhaust fan(s) in a dwelling or part thereof in which a conventionally flued natural draught gas appliance is installed can lead to a situation where normal flow does not develop (at least not for an unduly long period) or may be reversed (adverse flow) if normal flow had been established prior to the fan being turned on.
3. If adverse flow persists for a sustained period this can result in excessively high concentrations of combustion products accumulating in the indoor environment. Under some conditions these may include sufficiently high concentrations of carbon monoxide as to represent a hazard to health and even to life.
4. There is a large body of literature showing that negative pressures can result in adverse flow. While the reported values necessary to cause this condition vary from as low as one to a few Pascals they are all much lower than the negative pressure capability of a typical modern exhaust fan in a space with limited ventilation. This was also the result of work commissioned by the Energy*Safety* Division of the Western Australian Department of Commerce and conducted by the AGA in Melbourne.
5. Adverse flow may result in spillage of high levels of CO as a result of either of two scenarios:
    - Products from a poorly adjusted or maintained appliance producing CO, are spilled into the indoor environment, or
    - The down draught (that is, the adverse flow) affects the appliance's combustion processes and results in CO emission (despite the presence of a draught diverter).
6. Wind effects can also produce adverse flow conditions but these are expected to be much more transient than those produced by an exhaust fan(s) under an extended period of operation.
7. The potential safety issues associated with adverse flow have been recognised by gas authorities and others for many years, though the increased prevalence of exhaust fans and tighter dwellings has made the problem more critical. Some gas authorities and regulators (Including Energy Safe Victoria) recommend a test for a newly installed appliance under the most severe conditions of depressurisation as essential.
8. After conducting a wide range of tests into the issue of adverse flow caused by exhaust fans, it was concluded in a report commissioned by the UK regulatory authority HSE, that tests were required on each installation to establish the suitability to avoid adverse flow situations arising.

9. The use of CO alarms is sometimes advocated as a desirable measure to eliminate the threat of CO poisoning in dwellings – regardless of how it may be produced. However, there are significant issues related to the reliability, useful life, number required, positioning and cost of CO alarms. CO alarms are not linked into the gas supply of the appliance and to do so would require a more complex and costly design involving multiple trades. Retrofitting such a link would also be a major challenge on the scale required, considering there are an estimated 4.2 million dwellings in Australia where negative pressure conditions could affect combustion appliances. The cost of installing CO detectors in these would be 3.5 to 4 billion dollars as a base figure and up to $12B if a 10-year period is considered.
10. The use of CO alarms in recreational vehicles, which may use gas for space heating, water heating and refrigeration appears to be a slightly more suitable and cost effective solution. However the cost could still represent $100M per potential fatality.
11. Spill switches are devices that are linked into the gas supply and will shut down the appliance in the event of a flue blockage or partial flue blockage. However, in the event of a strong adverse flow spill switches may not be as effective. Depending on the situation, it is probable that the flue products may be excessively diluted by the outside air and not reach the required trip temperature.
12. Increasing the ventilation (free area of ventilators directly leading to the outside) can reduce the tendency for adverse flow to develop but may be incompatible with requirements to improve the thermal efficiency of buildings (such as under the 6 Star Rating scheme). Any additional ventilation installed will need to be large to ensure the pressure does not exceed this threshold pressure values as indicated in point 4 above.
13. Oxygen depletion sensors (ODS) have a metastable pilot flame which extinguishes if the level of vitiation of the combustion air becomes excessive (and regardless of how this occurred). They have been required on unflued space heaters in Australia for over 25 years. ODS's are robust devices that are inherently linked into the gas supply, which is cut off on activation of the ODS. They could be fitted to new models of gas appliance and appear to have merit as an option for addressing the issue of excessive adverse flow with future gas appliances. However ODS's are inferential devices that do not measure CO concentrations directly and may not provide protection in a case where an appliance was spilling combustion products containing an excessively high concentration of CO. Also retrofitting ODS's into existing appliances on the scale required appears impractical.
14. Appliance maintenance is recommended for all gas appliances every two years and, while not a measure to prevent or limit the development of negative pressures, it should ensure that CO emission from appliances so maintained is minimised.
15. The use of room sealed or forced draught appliances would, in all but the most unusual fault circumstances, ensure protection against the spillage of combustion products into living areas. However such appliances are expensive and retrofitting them in place of existing installations is impractical.
16. .A timer inserted in the electrical circuit of the exhaust fan(s) appears to be a viable option in reducing the possibility of extended periods of negative pressure caused by fan operation. It is envisaged that the timer would allow fan operation for a period of some ten minutes before being restarted. A further option is for a lock out period following a run. However such a control may be seen as an inconvenience by users.

17. A public awareness campaign on the potential hazards of situations, in which negative pressures are developed, while not effecting any physical protections, would be a method of raising awareness of the issues. Such a campaign would be expected to include advice that adequate ventilation must be provided (open doors and/or windows) during periods while exhaust fans are running or simply that exhaust fans and flued gas appliances must not be operated simultaneously. The campaign may include newspaper advertisements and bill inserts to gas customers and possibly stick-on notices for exhaust fan switches and gas appliances warning of the potential hazards. It may also note that the potential hazard extends to natural draught open flued combustion appliances that burn fuel other than gas.

18. Addressing the higher priority safety related items (engineering controls) is in accordance with recognised risk mitigation engineering techniques. It also avoids the issues associated with professional liability aspects of addressing lower ranked procedural controls (such as CO alarms without interruption to gas supply) before, or in isolation to, engineering controls are implemented. To illustrate the point, if there was a CO related fatality in a dwelling fitted with CO alarms then a subsequent coronial inquiry would most likely consider the risk model followed. CO alarms being a non-preferred control, also given the technical difficulties in their application and when used in isolation to other controls are not likely to substantially reduce the potential of CO fatalities. If it is then established that such non-preferred controls were (only) implemented the coroner would be well justified in making negative findings against the individuals who implemented such inappropriate risk model.

19. Implementing CO alarms overseas was only introduced after other, more effective means of achieving safety outcomes were pursued. These include improvements in appliance maintenance, appliance types and ventilation.

9 RECOMMENDATIONS

This investigation has revealed evidence to show that the operation of a conventionally flued natural draught gas appliance in a modern residence complying with the current National Construction Code has the potential to expose the residents to unacceptably high and even lethal levels of CO. At the same time, such installations do not comply with AS/NZS 5601.1:2010 Gas Installations, as appliances are not to be operated during periods of negative pressure under that standard. The likelihood of such exposure is expected to increase in the future with greater numbers of exhaust fans, reduced air infiltration levels in modern houses and with higher efficiency gas appliances. However, the available time and resources has not permitted a full investigation of the implementation of the possible mitigation measures.

Over the last decade the fatality rate has averaged one person per year nationwide. The full cost implications of possible mitigation measures needs to be considered so that available funds are utilised to the maximum advantage.

The magnitude of the problem identified herein is illustrated by the fact that there is an estimated 4.2 million dwellings in Australia where the possibility of negative pressure conditions affecting combustion appliances exists. The cost of installing CO alarms, without links to interrupt the supply of gas following an alarm condition, in these would be in the order of 3.5 to 4 billion dollars. In addition there would be ongoing cost for annual testing and regular replacement of alarms. The total lifecycle cost for residential CO protection alarms over a 10 year period is likely to exceed $12 Billion. The use of CO alarms in isolation does not address the underlying causes of CO poisoning that are identified in this report. The report does also identify a range of controls which will overcome the root cause of CO poisoning and thus positively reduce the likelihood of CO poisoning.

It is therefore recommended that a consultancy with access to suitably qualified personnel should be engaged to review the present report and other relevant literature and produce a quantitative risk assessment (QRA) of the issues raised. A QRA is required to fully understand regulatory impacts of the implementation of any potential mitigation measures. For this reason it is recommended that an RIS be deferred until the completion of a QRA.

It is recommended also that GTRC will be involved in the selection of this consultancy and that the terms of engagement are extended to include a review of the National Construction Code and its relationship with overseas construction standards and AS/NZS 5601.1:2010 Gas Installations.

10 REFERENCES

These include references that appear in the appendices

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Appendix A – Flow Reversal Theory

Flue Operation

Flue systems work due to the natural buoyancy of the warm products of combustion. This phenomenon creates a negative gauge pressure (suction) at the bottom of the flue, the flue draught.

The driving pressure for the stack effect can be estimated from the following equation:

$$\Delta P = 0.0342ah\left(\frac{1}{T_o} - \frac{1}{T_i}\right)$$

Where: a = atmospheric pressure (Pa)

h = stack height (m)

T_o = outside temperature (K)

T_i = inside temperature (K)

ΔP = driving pressure (Pa)

This equation, which can be derived from first principles using the densities of flue gas and external air, is approximate only. A more comprehensive analysis of flue performance can be found in reference 27.

If an opposing differential pressure greater than the driving pressure is created, either through a high external pressure or low internal pressure, the buoyancy effect will be overcome and the flow in the flue will reverse.

The above equation shows the importance of the temperature required to create flue draw. During the start-up period of an appliance prior to all components reaching operating temperature the flue draught is correspondingly lower.

For a typical residential installation, the flue draught can typically be expected to be in the order of Pascals.

Draught Diverter

The purpose of a draught diverter is to isolate the combustion system from the effects of pressure and flow changes in the secondary flue. A draught diverter may be integral or located in the flue system, immediately above the appliance [28] and consists of an opening and a baffle plate, as shown in Figure 1 below, which is as shown in reference 29.

During normal operation, room air is drawn into the draught diverter and mixes with the products of combustion. The diluted flue products then pass up the secondary flue.

During adverse conditions with downdraught in the secondary flue, the draught diverter is designed to direct the flow out of the diverter and into the surrounding environment. This is intended to prevent the back flowing gases from affecting the combustion process occurring in the appliance. If such a disturbance occurred it could cause flame abnormality, the consequences of which may include large amounts of CO generation.

However, it is to be noted that when operating as intended, a draught diverter will release the products of combustion into the indoor environment under conditions of adverse flow. It follows that if the burner of the appliance is faulty and produces high levels of CO under conditions of normal operation these can be expected to be vented from the diverter into the indoor environment. An alternative scenario is that of an appliance that operates satisfactorily under normal conditions but where a faulty or poorly designed draught diverter allows reverse flowing gases to enter the combustion chamber and possibly give rise to flame abnormality and CO production (such an observation has been reported in an HSE sponsored investigation [18]).

During conditions of updraught in the secondary flue, additional air is drawn through the draught diverter rather than from the primary flue. This allows for consistent conditions in the primary flue and combustion chamber and so prevents disturbance of the appliance operation.

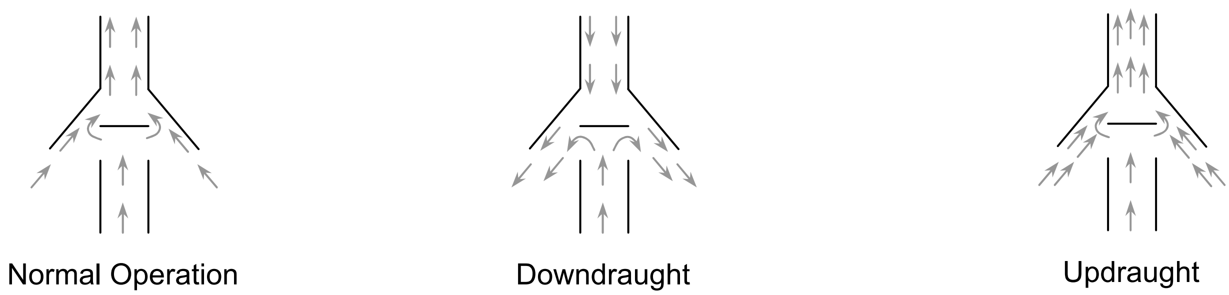

Figure A1. Schematic of draught diverter operation [29]

Exhaust Fan Operation

In a typical residential dwelling the operation of an exhaust fan(s) creates a negative gauge pressure within the living space. The degree of negative pressure created is dependent mainly upon the state of external doors and windows (open or shut), the size and number of fans and how well ventilated the house is.

Assuming that all external doors and windows are closed, the magnitude of the negative pressure developed will depend on the available ventilation openings. With a given type of fan in operation, a house with raised floorboards, ventilation openings and loose fitting doors will have a comparatively low negative pressure compared to a house with a concrete slab, rendered walls and weather strips on external doors. The chart below (Figure 2) shows the effect of altering the tightness of a house. The pressure loss through a vent is proportional to the square of the flow rate. The pressure and flow created by an axial fan is a characteristic of the particular model. However, they all show a similar shape with the developed pressure decreasing with increasing flow rate.

The exhaust system will operate at the point where the developed fan pressure equals the friction losses of the system. On the chart this balance point is where the two lines cross.

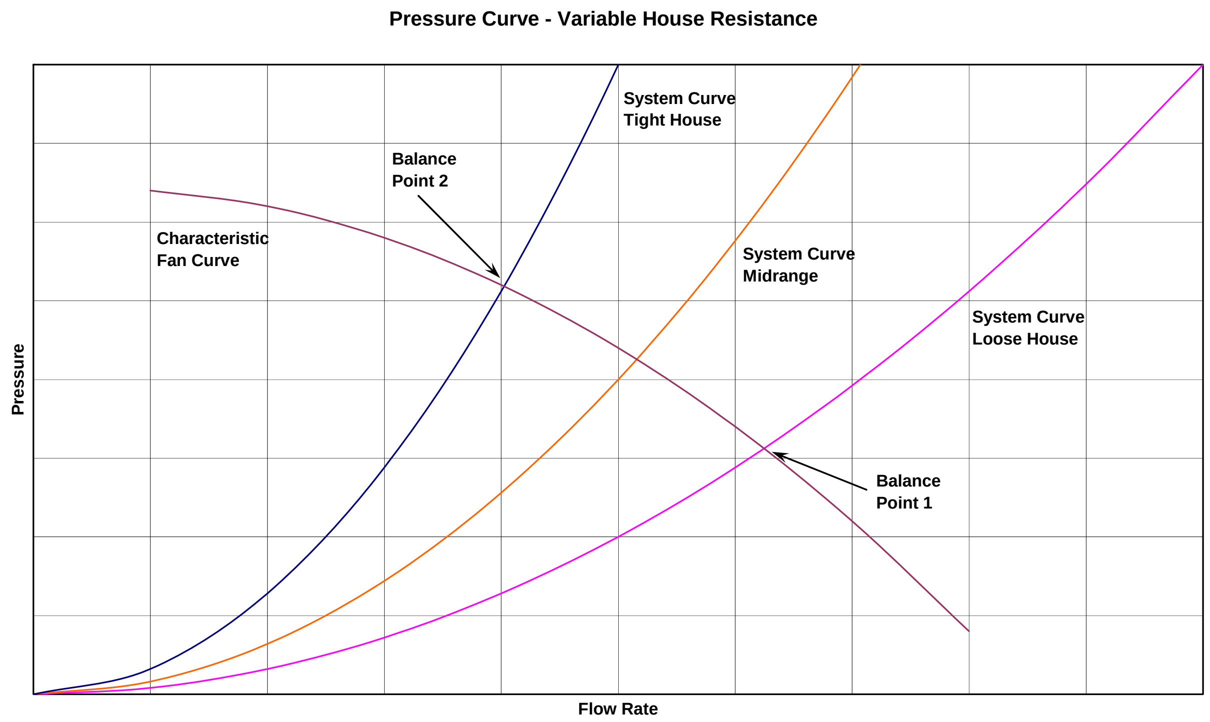

Figure A2. Typical fan curves showing balance points.

The effect of operating at different positions on the fan curve is illustrated in Figure A3 below. Assuming that the conditions on the discharge side of the fan do not change, the higher developed fan pressure for Balance Point 2 is accompanied by an increased negative pressure.

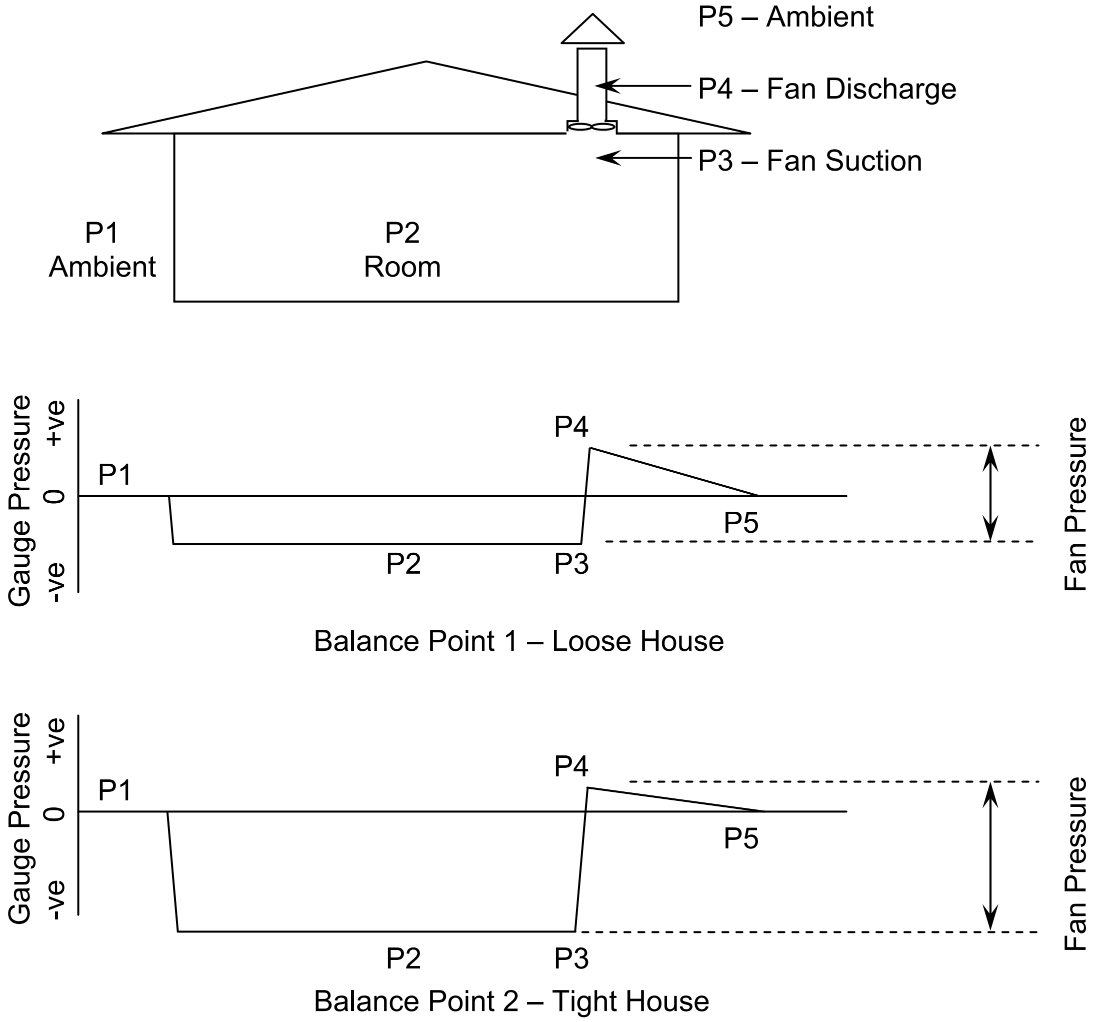

Figure A3. Fan operating schematic

Multiple Fans in Parallel

The use of multiple fans within a residence will also affect the room pressure. Two identical fans connected in parallel will double the flow rate on the fan curve for a given developed pressure (blue line compared to the pink line). The effect on the system of increasing the flow rate results greater pressure losses as shown in figure A4 below. The net effect of operating two fans is not only an increase in flow rate, but an increase in developed pressure. .

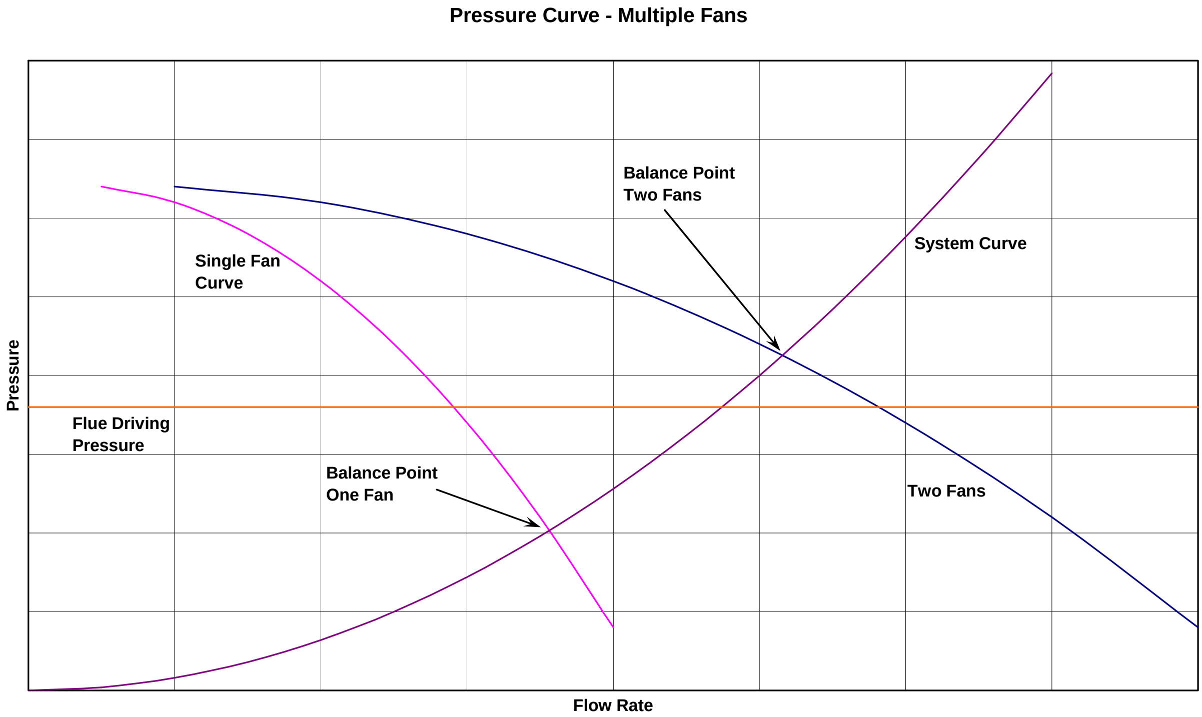

Figure A4 – Fan operation in parallel

Combined Effect

Consideration of the above principles show that both the flue draught of a gas appliance and the operation of an exhaust fan act to reduce the room air pressure. The exhaust fan produces a negative pressure in the house which detracts from the driving force of the flue. With a significant negative pressure, the flue draught may be completely overcome and the flue products consequently drawn into the living space.

Figure 3 has been recreated below (as Figure 5), with the inclusion of the flue draught. As can be seen, by reducing the ventilation area of the house the flue draught can be exceeded. If this occurs, the flow through the flue will be reversed as above.

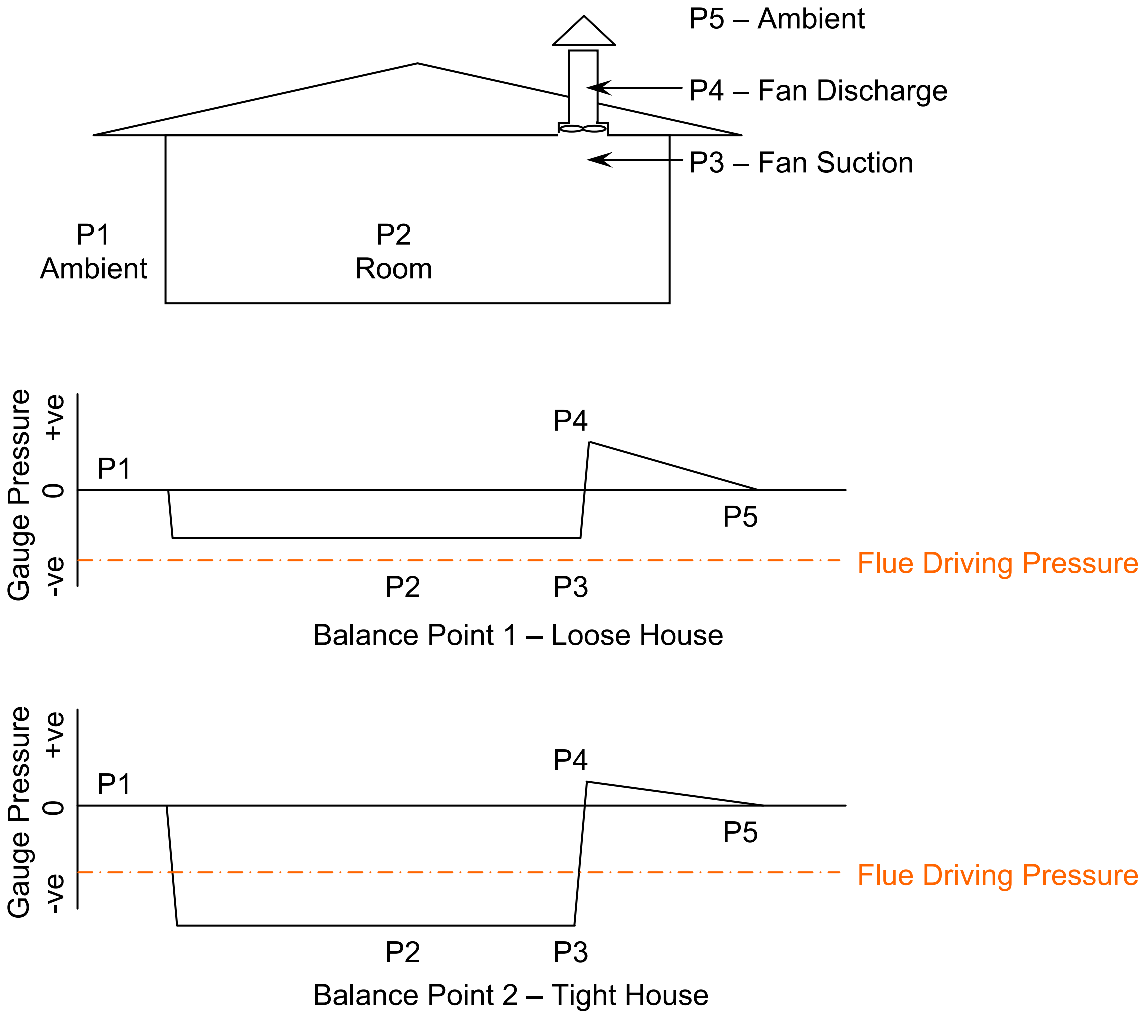

Figure A5 Schematic including flue draught and fan operation

Appendix B – Flow Reversal Tests

As noted in the report proper, the Australian Gas Association was commissioned to carry out the testing at its laboratories in Braeside, Victoria. In these tests, the method of which is fully described in the attached report, a Vulcan Quasar heater was operated in test room of volume 13.9 m^3 with restricted air inlets and an exhaust fan. The principle of the tests was to operate the heater under different conditions and determine the level of negative pressure necessary to effect a flow reversal in the flue, that is, to change the flow from normal to adverse. Also tested was the maximum level of negative pressure under which normal flow could be established. The report from AGA dealing with these tests is attached below.

Inspection of the results contained in the report shows that the level of negative pressure required to effect a flow reversal when the heater was operating was typically less than 4 Pa and as low as 2 Pa in one case. The negative pressure required to prevent normal flow establishment was, as might be anticipated, even lower at between 1 and 2 Pa

AGA LABORATORY REPORT

Report Number:	R11032302
Date of Issue:	2/05/2011
Testing dates:	28/03/2011 – 17/04/2011
Description:	Secondary Flue Adverse Flow Testing

ISSUED TO

Customer Name	EnergySafety WA – Department of Commerce
Address	Level 1, 303 Sevenoaks Street, Cannington WA 6107
Contact Person	Cornelis De Groot

TESTING OFFICER

Name	Robert Vukman
Signed	

AUTHORISING OFFICER

Name	Vasilios (Billy) Tabourlos
Signed	

CONTENTS

The results contained herein apply to the particular sample/s tested at the time of testing and to the specific tests carried out as detailed in this Test Report. The issuing of this Test Report does not indicate or imply any measure of approval / certification / recommendation / guarantee/ endorsement of any product / manufacturer / supplier / user.

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INTRODUCTION

EnergySafety WA – Department of Commerce (ESWA) commissioned the AGA Laboratory to conduct a range of specified tests to determine the functionality and characteristics of the flue operation of an open flued domestic space heating appliance. In particular, the tests involved flow reversal and flow establishment of flue products for an open flued wall furnace and was designed to simulate the flue operation of a domestically installed wall furnace and the effect household exhaust fans may have on the functional performance of the appliance flue.

The method of test provided by ESWA incorporated ten scenarios involving variation in gas rate, gas conditions, exhaust fan types and speeds, advantageous ventilation, circulation fan and outside ambient temperature.

BACKGROUND

It has been suggested negative pressure developed inside a dwelling by household exhaust fans could, in certain circumstances, adversely affect normal operation of an open flued gas space heating appliance, such as a wall furnace. This could lead to "flow reversal" of flue products into the habitable (heated) space via the appliance draught diverter instead of being vented (flued) to the outside. The term "*backdrafting*" has been used in some literature to describe this phenomenon, however, this report will refer to it as ***"flow reversal"***.

The rate of flow reversal could be affected by many factors, such as burner capacity and rate (setting), appliance circulating fan capacity and speed, exhaust fan capacity and speed, advantageous ventilation and outside ambient temperature.

In the event a household exhaust fan (or fans) are operating prior to turning on an open flued appliance, a negative pressure (i.e. a pressure lower than outside ambient) may already exist. In this circumstance, the moment the flue commences operation as designed and intended will be referred to as **"flow establishment"** in this report.

Refer to Appendix B for more information.

TEST PROGRAMME

The ESWA Test Programme is outlined in Appendices B and C, where the testing was conducted in a sealed temperature controlled room of volume 2450(h) x 2410(w) x 2360(l) mm^3.

The Method of Test outlines the two series of tests:

1) "**Flow Reversal**" test, and;
2) "**Flow Establishment**" test.

Both series of tests required the recording of pressures, temperatures, Carbon Monoxide (CO), Carbon Dioxide (CO_2), Oxygen (O_2) and Humidity (H_2O concentration levels).

The Extraction fans used were:

a) Fantech RP202 (0.07kW, 0.31A, 230-240V) exhaust fan, and;
b) Fasco IXL8XFSBT (25W, 0.17A, 240V), branded as 'IXL Ventair 200 Model 10320, ceiling exhaust fan.

TESTED SAMPLE AND MEASUREMENT DETAILS

AGA Sample No. 11032302/1

Serial No. Marked 48235 (Year: 1986)

Nominal Hourly Gas Consumption 26.4 MJ/h on Maximum and 10MJ/h on Turndown

A second hand Vulcan Quasar wall furnace was acquired and serviced in accordance with manufacturer's instructions. The appliance was checked for correct operation prior to commencing testing, and was installed in accordance with the manufacturer's installation instructions.

The measured gas consumption details are as follows:

Setting	Maximum	Turndown
Nominal Hourly Gas Consumption (MJ/h)	26.4	10
Determined Hourly Gas Consumption (MJ/h)	26.38 ± 0.27	9.75 ± 0.11
Percentage variation (%)	-0.07 ± 1.03	-2.47 ± 1.08

The measurements were taken in accordance with the Test Programme outlined in Appendices B and C, and in particular the points referred to throughout this report are as detailed overleaf:

On Appliance

Other measurements as specified in Appendix B

- Ambient temperature, Ta
- Ambient pressure, Pa
- Room temperature, Tr
- Room relative humidity, Hr
- Room: CO, CO_2, O_2
- Room ventilation area, Ar
- Pressure differential, ΔP

SAMPLE MODIFICATIONS

No modifications were made to the test sample.

CHANGES TO ORIGINAL AGREED TESTING

No Changes to the original agreed testing were made.

UNCERTAINTY OF MEASUREMENT

Uncertainties of measurement reported in this report have been calculated in accordance with the principles of ISO-GUM at a confidence level of 95% and coverage factor 2.1, unless otherwise specified.

Temperatures:	± 1°C
CO:	± 6 ppm
CO2:	± 0.1%
O2:	± 0.5%
ΔP:	± 0.05 Pa
Pa:	± 0.01 kPa
Hr:	± 2%
Ar:	± (5mm x 5mm)

RESULTS

Flow Reversal Test

		Test 1	Test 2	Test 3	Test 4	Test 5	Test 7
		Baseline Test	Turndown	Low Fan	Low Ambient	High Airflow	Ceiling Fan
AMBIENT	Ta (°C)	23.8	23.2	23.9	10.2	19.2	19.3
	Pa (kPa)	101.85	102.65	101.85	102.50	101.38	102.14
ΔP (Pa)		3.6	2.0	4.3	3.6	3.5	3.7
ROOM	Tr (°C)	25.6	21.5	25.8	11.6	18.5	21.0
	Hr (%)	44.8	39.6	40.4	56.2	49.9	50.1
	CO (ppm)	2.8	0.4	14.5	0.0	0.0	0.9
	CO_2 (%)	0.52	0.13	0.48	0.20	0.06	0.14
	O_2 (%)	20.1	20.7	20.1	20.6	20.9	20.9
	Ar (mm^2)	Closed	Closed	Closed	Closed	440 x 315	220 x 145
FLUE	T1 (°C)	183.8	107.4	216.0	179.2	183.3	178.8
	T2 (°C)	115.0	77.8	117.0	120.8	124.3	125.7
	T3 (°C)	104.8	72.9	114.4	115.4	123.3	114.2
	T4 (°C)	79.6	62.2	84.7	93.9	101.6	93.9
	CO (ppm)	16.6	37.0	39.0	1.2	2.8	2.1
	CO_2 (%)	7.71	2.95	7.39	6.22	5.60	6.64
	O_2 (%)	8.0	16.1	8.6	10.9	11.5	10.5
DRAFT DIVERTOR AND AERATION	Td1 (°C)	123.9	75.4	157.7	90.8	44.3	108.9
	Td2 (°C)	114.5	62.4	156.7	77.4	40.9	89.9
	Td3 (°C)	80.7	55.5	106.4	60.6	35.0	65.0
	CO (ppm)	2.5	0.1	13.9	0.1	0.1	0.9
	CO_2 (%)	0.52	0.14	0.50	0.19	0.06	0.14
	O_2 (%)	20.2	20.8	20.1	20.6	20.8	20.8
RUNNING TIME (min) *		45	10	48	20	20	20

* Total time appliance was running over all the iterations required to achieve ΔP.

Flow Reversal Test – Overload Combustion (Test 6a and 6b)

	Fantech Fan (Test 6a)				IXL Ceiling Fan (Test 6b)			
	Raw Data		Normalised		Raw Data		Normalised	
Time (min)	CO (ppm)	CO_2 (%)	CO (ppm)	CO_2 (%)	CO (ppm)	CO_2 (%)	CO (ppm)	CO_2 (%)
0	0	0.044	0	0	0.1	0.12	0	0
1	1.3	0.183	1.3	0.139	15.3	0.177	15.2	0.057
2	3.6	0.202	3.6	0.158	36.7	0.182	36.6	0.062
3	6	0.167	6	0.123	44.5	0.185	44.4	0.065
4	12.1	0.164	12.1	0.12	68.5	0.2	68.4	0.08
5	21.3	0.158	21.3	0.114	79.9	0.211	79.8	0.091
6	25.6	0.17	25.6	0.126	94.6	0.226	94.5	0.106
7	30.9	0.162	30.9	0.118	127.2	0.264	127.1	0.144
8	34.6	0.168	34.6	0.124	147.6	0.285	147.5	0.165
9	38.4	0.163	38.4	0.119	169.9	0.297	169.8	0.177
10	51.1	0.156	51.1	0.112	191.2	0.317	191.1	0.197
11	42.6	0.157	42.6	0.113	207.9	0.325	207.8	0.205
12	47.4	0.154	47.4	0.110	216.9	0.337	216.8	0.217
13					233.5	0.345	233.4	0.225
14					238.9	0.347	238.8	0.227
15					243.7	0.353	243.6	0.233

Note 1: Test sample was operated normally for 20 minutes before the reverse flow overload condition was applied.

Note 2: In both cases 6a and 6b, the measured Carbon Monoxide concentration in the flue was greater than 3000ppm while the appliance was operating at an overload condition on Na gas with normal flueing.

Note 3: In Test 6a, a ΔP of 10 Pa was achieved with a room ventilation area, Ar, of 300mm x 300mm.

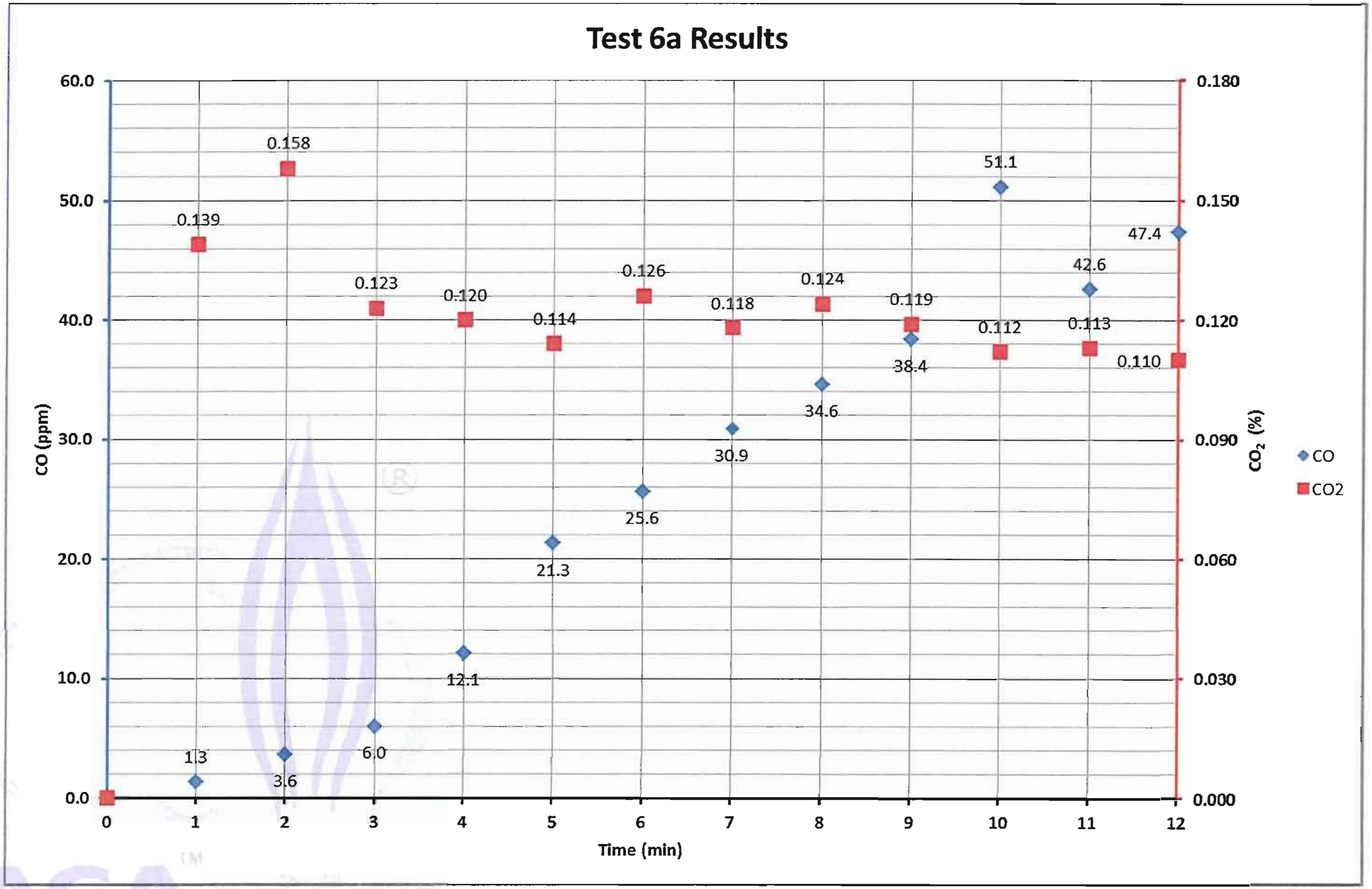
Note 4: In Test 6b the ventilation room ventilation area, Ar, required for adverse flow was 220mm x 135 mm which achieved a ΔP of 3.9 Pa.

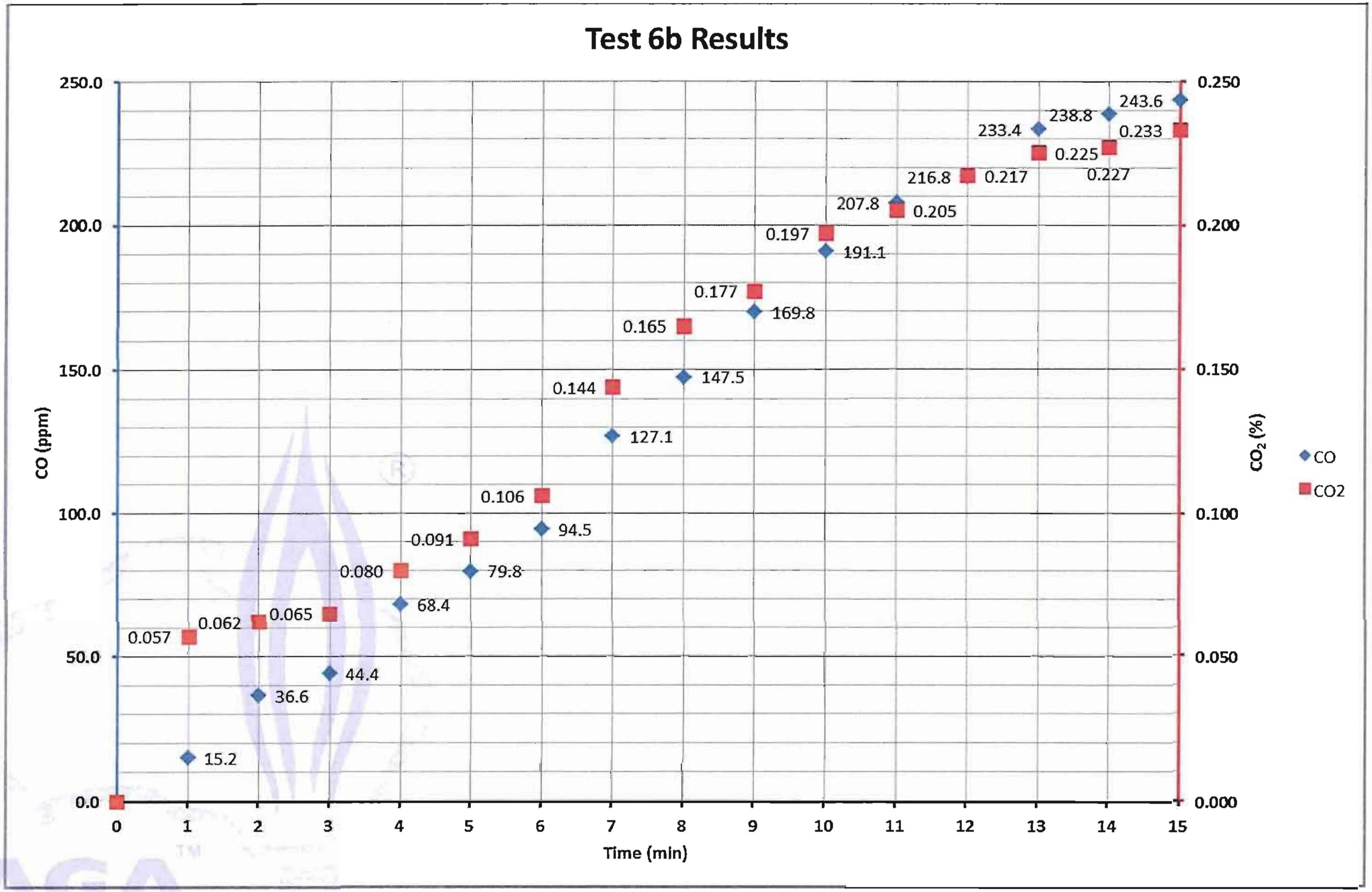
Appendix A illustrates the graphs for the results obtained above.

Flow Establishment Test

		Test 8	Test 9	Test 10	Test 11	Test 12
		Baseline Test	Turndown	Low Fan	Low Ambient	High Airflow
AMBIENT	Ta (°C)	26.6	27.0	26.7	10.0	18.5
	Pa (kPa)	102.70	102.90	102.90	102.50	101.38
ΔP (Pa)		1.6	1.1	2.0	1.4	1.6
ROOM	Tr (°C)	25.4	26.8	27.8	11.3	19.6
	Hr (%)	43.7	50.5	36.9	48.2	55.2
	CO (ppm)	0.0	0.0	23.4	0.0	0.0
	CO_2 (%)	0.24	0.17	0.349	0.13	0.05
	O_2 (%)	20.7	20.6	20.3	20.7	20.9
	Ar (mm^2)	Closed	Close	Closed	Closed	460 x 540
FLUE	T1 (°C)	156.2	102.3	190.2	127.8	123.0
	T2 (°C)	95.8	69.0	120.2	79.9	83.9
	T3 (°C)	97.3	70.1	118.9	83.0	82.1
	T4 (°C)	80.9	56.4	100.3	65.4	70.7
	CO (ppm)	15.0	31.6	1223*	0.4	0.6
	CO_2 (%)	5.95	2.89	5.51	5.97	5.56
	O_2 (%)	11.1	16.3	11.8	11.2	12.2
DRAFT DIVERTOR AND AERATION	Td1 (°C)	55.0	55.1	63.1	52.3	33.4
	Td2 (°C)	54.9	54.6	66.5	54.8	35.4
	Td3 (°C)	52.0	45.2	64.0	35.5	32.2
	CO (ppm)	0.0	0.0	19.0	0.0	0.0
	CO_2 (%)	0.22	0.16	0.30	0.13	0.06
	O_2 (%)	20.8	20.7	20.4	20.7	20.9

*The Carbon Monoxide concentration dropped to ~400ppm after 3-4 min of appliance operation.


Test 6a Results
60.0
50.0
40.0
30.0
20.0
10.0
0.0
CO (ppm)
0.180
0.150
0.120
0.090
0.060
0.030
0.000
CO_2 (%)
0.158
0.139
0.123
0.120
0.114
0.126
0.118
0.124
0.119
0.112
0.113
0.110
1.3
3.6
6.0
12.1
21.3
25.6
30.9
34.6
38.4
51.1
42.6
47.4
0 1 2 3 4 5 6 7 8 9 10 11 12
Time (min)
CO
CO2


Test 6b Results
CO (ppm)
CO₂ (%)
Time (min)
CO
CO2
250.0
200.0
150.0
100.0
50.0
0.0
0.250
0.200
0.150
0.100
0.050
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
15.2
36.6
44.4
68.4
79.8
94.5
127.1
147.5
169.8
191.1
207.8
216.8
233.4
238.8
243.6
0.057
0.062
0.065
0.080
0.091
0.106
0.144
0.165
0.177
0.197
0.205
0.217
0.225
0.227
0.233

Secondary Flue Adverse Flow Test Proposal

1. Background

There is evidence that the draught developed in the secondary flue of an internally located open flued gas appliance may, in certain circumstances, be overcome by the local depressurisation generated by the operation of an exhaust fan or fans. This, in turn, can lead to "adverse" flow (rather than the intended "normal" flow), where outside air flows down the secondary flue pipe and into the internal heated space. This causes the release of the combustion products from the appliance into the interior occupied space. The term "backdrafting" is widely used in US literature to describe adverse flow.

The circumstances in which adverse flow may occur would primarily relate to the capacity of any exhaust fans that communicated with the space in which the appliance is installed as well as the level of ventilation and the heat input rate of the burner(s). It will also be affected by external weather conditions and the internal-external temperature differential.

It is likely that a situation in which, for whatever reason, the pressure inside a house was lower than outside when an appliance was started the "natural draught" required for normal flow may not develop (or may take an excessively long time to do so) while the depressurisation existed.

In order to tests this effect two sets experiments are proposed in which a flued gas appliance is operated within a test room that is well sealed except for an adjustable vent that can be used to vary the rate of air flow into the test room. A variable speed exhaust fan capable of an air flow of 200 l/s and of developing a static pressure of 100 Pa is also fitted into the room, in order to develop the required pressure reduction required for the tests. A wall furnace is proposed as the appliance to be used with a heating capacity of 26 MJ/h.

The standard ASTM E1998-02 (2007) entitled "Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances" addresses the question of adverse flow of the type noted above. It is significant that, while presenting various methods, it is mentioned in the ASTM that "Although a number of different methods have been used to assess backdrafting and spillage .... a single well-accepted method is not yet available." The methods proposed below have numerous similarities to those in the ASTM.

2. Method of Test

2.1 Principle

Two series of tests are conducted.

- Flow Reversal Test: in this test a "naturally flued" appliance is started in a test room where the pressure is equal to or slightly greater than the external atmosphere in which its flue terminates. The pressure in the test room is reduced in steps until adverse flow is observed in the secondary flue and the minimum depressurisation that can produce adverse flow has been established.
- Flow Establishment Test: In this test series the room is depressurised with respect to the area in which the secondary flue of the appliance terminates (which will generate a pre-existing adverse flow in the flue). The appliance is started and it is observed whether the tendency to produce a natural draught in the flue can overcome the depressurisation within a specified time. The test is repeated with various pre-existing depressurisation levels until the (approximate) maximum level that can be overcome by the natural draft has been found.

In both test series, the experimental arrangement is instrumented with measurements of pressures, temperatures, CO, CO_2, O_2 and H_2O concentration levels and flow velocities and rates. The heaters are fuelled with natural gas only in these tests.

2.2 Flow Reversal Test

2.2.1 Materials

a) Specified gas at normal test gas pressure.

2.2.2 Apparatus

a) Equipment as specified in Clause 3.2.6 of Australian Standard AS 4553, including a simulated secondary flue and approved cowl

b) A vitiation room of known volume, capable of being sealed from outside air and in which the temperature can be controlled to ambient conditions. The vitiation room must be located within a larger enclosed area which is free from accidental draughts

c) Room air-mixing fan or equivalent means of ensuring a homogeneous room atmosphere without the creation of significant draughts

d) Carbon monoxide analyser, calibrated to give accurate and reproducible results in the order of 10 to 500 ppm concentration or better and capable of fast response

e) Carbon dioxide analyser, calibrated to give accurate and reproducible results in the order of 0.5 to 10% concentration or better and capable of fast response

f) At least three flue gas and room atmosphere sampling probe(s) capable of being switched to the CO/CO_2 and O_2 analysers in turn

g) At least eight flue gas and room temperature sensors

h) Flow velocity measuring device for the flue gases which does not cause significant impedance to the flow (a pitot tube or hot wire anemometer may be suitable)

i) At least one differential pressure measuring device (manometer) accurate to 0.1 Pa or better with a range of at least 50 Pa

j) Four manometers accurate to 1.0 Pa or better and with a range of at least 250 Pa.

k) A room atmosphere humidity recorder

l) Variable speed extraction fan and Fantech RP202 ceiling exhaust fan

m) Off the shelf ceiling exhaust fan

n) Manually operatable damper (nominal size 100 x 100mm) set near floor level of the vitiation room

o) A means of remotely starting and stopping the appliance (that is, without entering the vitiation room)

p) Oxygen analyser capable of reading in the range of 0-21% and capable of fast response

q) A suitably sized wall furnace adjustable to operate at a heat input rate of below 3 MJ/(m^3.h) with minimum length of flue pipe and approved cowl

2.2.3 Preparation of apparatus

a) Set up the appliance in accordance with Clause 3.2 of AS 4553

b) Ensure that the appliance is protected from any accidental draughts particularly those produced by operation of the room air-mixing or extraction fans.

c) Ensure that the thermostat or any other variable restriction in the gas line will not vary the gas flow rate during the test from the specified value.

d) Bypass any controls which restrict the operation of the fan due to low heat-exchanger temperature.

e) Connect the appliance to the gas supply.

f) Connect the appliance to the electricity supply (if required).

g) Fit the appliance with only the minimum length of flue permitted in the manufacturer's instructions and an approved cowl.

h) Position CO, CO_2 and O_2 sampling probes in the geometric centre of the room, in the approximate vicinity of the appliance air intake and at the midpoint of the flue pipe. The humidity is measured only at the room centre

i) Fit temperature probes approximately in the geometric centre of the room, in the approximate vicinity of the air intake. Also fit temperature probes at a point about 1 m away from (i.e. external to) approximately in the geometric centre of two opposite faces of the vitiation room and two at well separated points above the ceiling (the purpose is to obtain an average of the external temperature).

j) Fit temperature points set at the approximate centre of the secondary flue, two on the draught diverter and one in the primary flue. See Detail A

k) Fit a differential pressure probe with one point in the approximate geometric centre of the room and the other point exterior to the room. This probe must be accurate to 0.1 Pa, as in (i) of Section 2.2.2 above. Note that care must be taken to ensure that the probe measures only static pressure and are not influenced by currents or draughts

l) Fit two differential pressure probes (for low and high level measurement) with the interior points in the approximate geometric centre (one 100mm above floor level and one 100mm below ceiling level) and the other point exterior to the room. This probe must be accurate to 1 Pa, as in (j) of Section 2.2.2 above. Note that care must be taken to ensure that the probe measures only static pressure and are not influenced by currents or draughts

m) Fit flow velocity measuring in a central location in the secondary flue. Non directional devices such as hot wire anemometer are acceptable.

See diagram 1 for the layout.

2.2.4 Preliminary Test

Before proceeding to the test proper confirm that the appliances gas consumption and CO emissions (as measured by the CO/CO_2 ratio) are acceptable for a natural gas fired appliance subjected to typical installation conditions.

2.2.5 Procedure

a) Operate the appliance on the full capacity with normal test gas pressure at appliance inlet with the vitiation room door open and the cooling in operation. After 5 minutes take all readings of temperatures, pressures and flow velocity in the secondary flue. The extraction fan must be off and the vents fully open at this point. The vitiation room temperature should be controlled to ± 2°C of the exterior temperature during the test and normal flow in the flue must be confirmed.

b) With the heater operating at the rate set in (a), seal the vitiation room openings and start the extraction fan on low speed. Increase the extraction fan speed until an average pressure differential of approximately 2.0 Pa is developed between the exterior and interior of the vitiation room. Allow the temperatures, pressures and flow velocity in the secondary flue to stabilise and record all data.

c) If the differential pressure developed in (b) does not produce adverse flow in the secondary flue increase the fan speed until an average differential of 4.0 Pa has been developed. Alternatively, if the differential developed in (b) did produce a flow reversal, turn off the appliance and repeat steps (a) and (b) but with only 1.0 Pa differential in (b).

   Note: A reversal in flow in the flue will be indicated by an increase in the O_2 level measured the flue gas and a fall in its temperature as well as its velocity reducing and passing through zero before reversing.

d) Continue the above sequence until it is determined to within the smallest reliably measureable value (0.1 Pa) what is the minimum differential pressure (exterior to interior of the vitiation room) that overcomes the natural draught of the flue (and hence produces adverse flow).

e) Repeat steps (a) to (d) with the circulation fan turned to low speed.

f) Repeat steps (a) to (d) with the fan returned to high speed and set the appliance main burner to operate at the minimum gas rate.

g) Repeat steps (a) to (d) with the gas rate returned to full and with an ambient temperature of 10 Deg C or less.

h) Repeat steps (a) to (d) at normal ambient conditions and using the ceiling exhaust fan at full operational speed. The pressure differential within the room will need to be controlled by restricting the damper. Note, in order to achieve this, the damper free area will need to be increased to 200mm x 200mm.

i) Repeat steps (h) replacing the Fantech ceiling fan with an off the shelf ceiling fan, operating at full speed.

j) Repeat step (a) running the appliance on high Wobbe Index gas (minimum 55MJ/m3) and increasing the burner pressure until the appliance produces CO in excess of normal anticipated values.

   Operate the Fantech ceiling fan at full speed and set the damper such that the flue will reverse flow (anticipated to be 10-20 Pa room pressure).

   Due to safety concerns this test will need to be terminated after 15 minutes, the CO recording at the room centre exceeds 400ppm or a dangerous build up of CO is anticipated.

k) Repeat step (j), using the off the shelf fan

l) Conclude the test.

2.3 <u>Flow Establishment Test</u>

2.3.1 Materials

As in 2.2.1 above

2.3.2 Apparatus

As in 2.2.2 above

2.3.3 Preparation of apparatus

As in 2.2.3 above

2.3.4 Preliminary Test

As in 2.2.4 above

2.3.5 Procedure

a) Set the vitiation room to a temperature should be controlled to ± 2°C of the external temperature during the test.

b) With the cooling system still in operation, seal the vitiation room and start the extraction fan on low speed. Increase the fan speed until an average pressure differential of approximately 2.0 Pa is developed (ie the room interior is depressurised 2.0 Pa relative to the exterior).

c) Under the conditions developed in (b) remotely ignite the heater (full rate) and allow it to operate for 5 minutes. During that period observe whether normal or adverse flow develops in the flue and record all measurements. If the flow is adverse allow another 5 minutes of operation to determine if normal flow develops in the additional period.

d) Allow secondary flue to cool to room temperature

e) If the flow observed in (c) was normal repeat the steps from (a) but with approximately 4.0 Pa average differential. Alternatively, if the flow was adverse, repeat the steps from (a) but with approximately 1.0 Pa in step (b)

f) Continue the above sequence until the maximum initial central differential pressure (exterior to interior of the vitiation room) at which normal flow can develop within 10 minutes has been established.

g) Repeat steps (a) to (f) with the circulation fan turned to low speed.

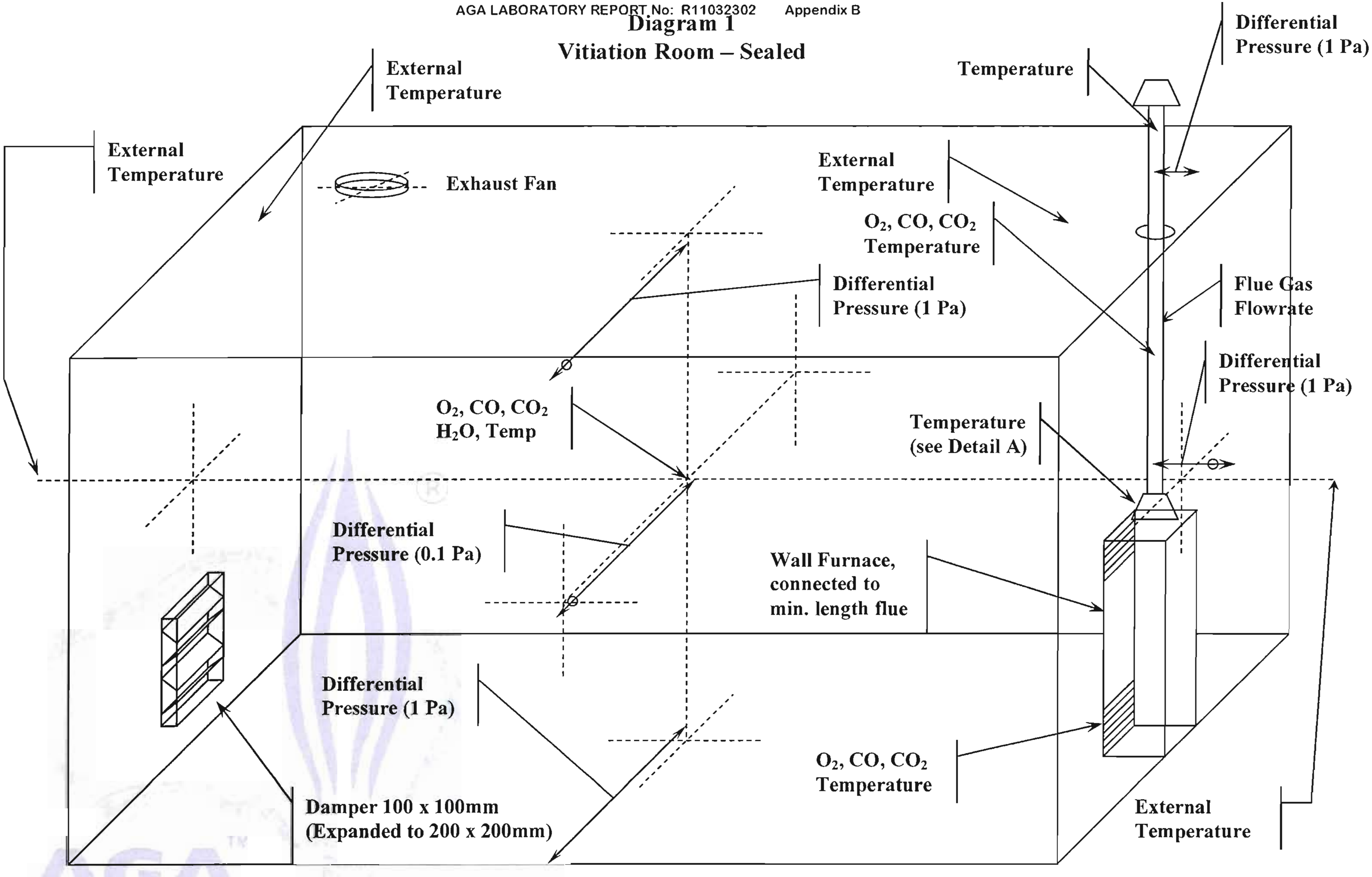
h) Repeat steps (a) to (f) with the fan returned to high speed and set the appliance main burner to operate at the minimum gas rate.

i) Repeat steps (a) to (f) with the gas rate returned to full and with an ambient temperature of 10 Deg C or less.

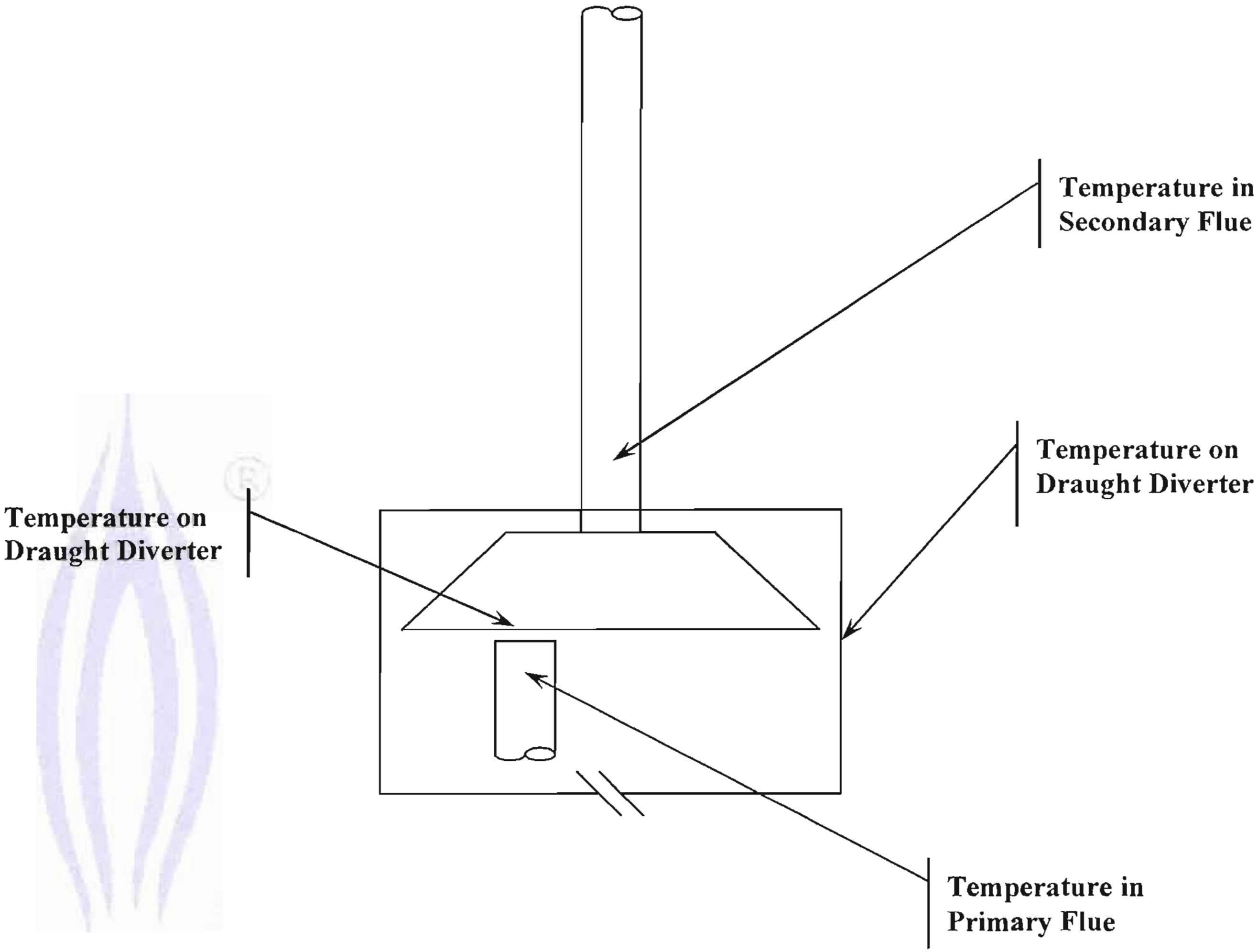
j) Repeat steps (a) to (f) at normal ambient conditions and using the ceiling exhaust fan at full operational speed. The pressure differential within the room will need to be controlled by restricting the damper. Note, in order to achieve this, the damper free area will need to be increased to 200mm x 200mm.

k) Conclude the test.

Diagram 1
Vitiation Room – Sealed



Detail A
Elevation of Appliance



Flow Reversal Test

	Test 1 Baseline Test	Test 2 Turndown	Test 3 Low Fan	Test 4 Low Ambient	Test 5 High Air Flow	Test 6a Overload	Test 6b Overload	Test 7 Ceiling Fan
Gas Rate	Full	Minimum	Full	Full	Full	Full	Full	Full
Gas Conditions	Line	Line	Line	Line	Line	**Overload	**Overload	Line
Fantech Fan Speed	Controlled	Controlled	Controlled	Controlled	Full	Full	Not Used	Not Used
Alternate Fan	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	Full	Full
***Damper Position**	Closed	Closed	Closed	Closed	Controlled	Controlled	Controlled	Controlled
Circulation Fan	High	High	Low	High	High	High	High	High
Ambient Temperature	Day	Day	Day	Low	Day	Day	Day	Day

* In order to control, approx 40 000mm^2 (200 x 200) area is likely to be required
** Additional safety requirements required, refer to MOT

Flow Establishment Test

	Test 8 Baseline Test	Test 9 Turndown	Test 10 Low Fan	Test 11 Low Ambient	Test 12 High Air Flow
Gas Rate	Full	Minimum	Full	Full	Full
Gas Conditions	Line	Line	Line	Line	Line
Fantech Fan Speed	Controlled	Controlled	Controlled	Controlled	Full
Alternate Fan	Not Used	Not Used	Not Used	Not Used	Not Used
Damper Position	Closed	Closed	Closed	Closed	Controlled
Circulation Fan	High	High	Low	High	High
Ambient Temperature	Day	Day	Day	Low	Day

END OF AGA LABORATORY REPORT No: R11032302

Appendix C – House Tightness Test

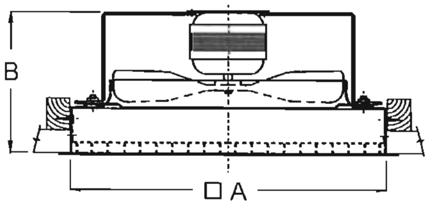
House tightness or ventilation rates may be tested by the decay rate of a tracer gas (10, 13) or the rate of addition to the space under test of the gas to maintain a given concentration (10). Alternatively, the dwelling under test may be subjected to a partial vacuum (of typically 50 Pa) and the air flow measured [10, 11, 30]. The latter method involves much higher pressure deficits than would normally occur due to natural ventilation, but gives a rapid method of comparing houses [10]. In some cases up to eight pressure difference points have been used to obtain the air leakage coefficient [11]. A Canadian standard [31] describes the determination of the air tightness of building envelopes by fan depressurization.

It is intended to carry out tests on a number of dwellings subsequently, however, as of June 2011 this has not been possible.

Appendix D – Published Fan Curves

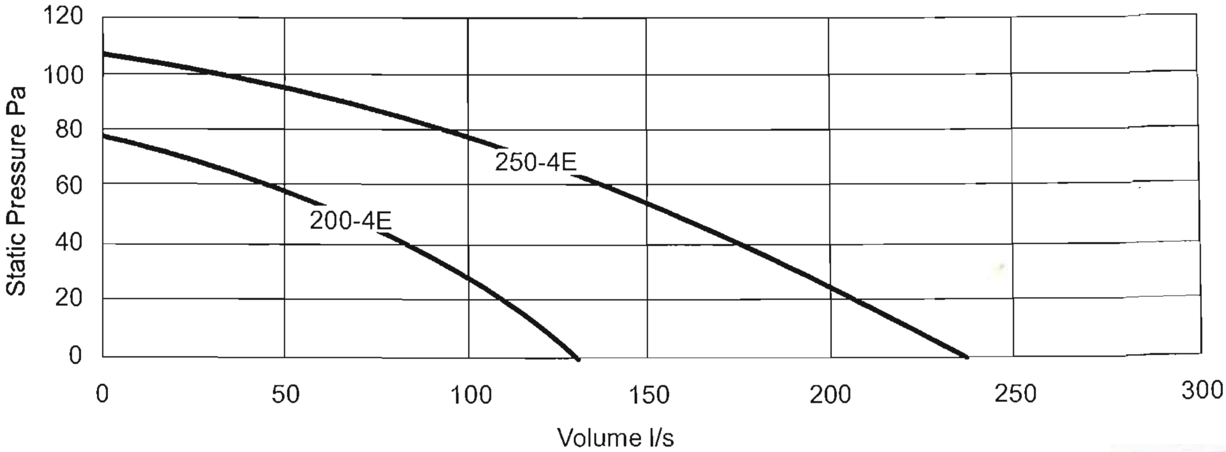
Attached below are several published fan curves of commercially available exhaust fans.

Dimensions



Size	A	B	Kg
200	345	150	5
250	345	150	5

Performance Curves for CEA



Technical Data

Model	Fan Speed r/s Nom	Single Phase		dBA @3m	Sound Power Level dB RE 10^{-12} W Free Field Method							
		Nom kW	Nom Amps		63	125	250	500	1K	2K	4K	8K
CEA200-4E	22	0.032	0.20	37	-	52	48	46	43	35	32	-
CEA250-4E	22	0.038	0.23	41	-	55	51	49	46	38	35	-

EN Series - EN20

Location

Designation

Project

Notes

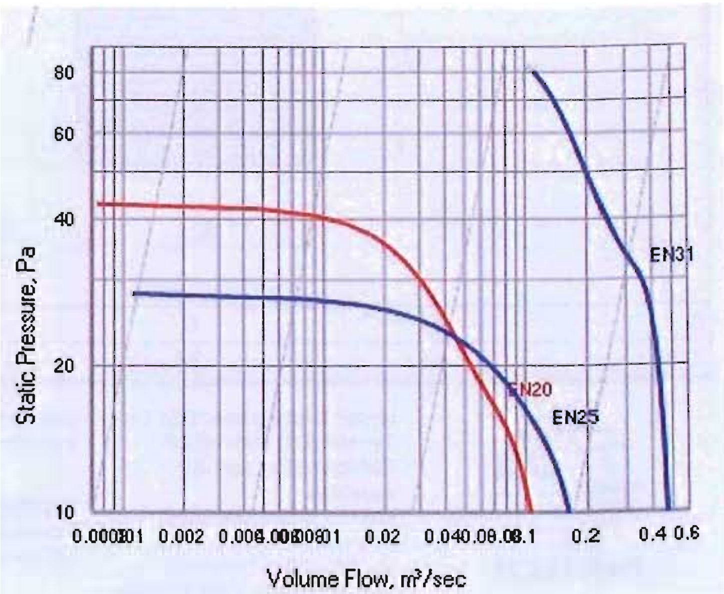
FEATURES

The EN Series can be wall or ceiling mounted and is a high quality range of fans suitable for exhausting from homes as well as business premises such as cafes, schools, swimming pools, offices, toilets, shower rooms, etc.

Construction
Housings are white and of weather and impact-resistant plastic.

Motors
Type - shaded-pole induction motor.
Electricity supply - 220-240V, single-phase, 50Hz.
Bearings - sealed-for-life ball bearings.
Maximum ambient temperature - 40°C.
Speed-controllable.
Protection - IP20.

Internal Thermal Protection
Auto-reset type are fitted as standard.

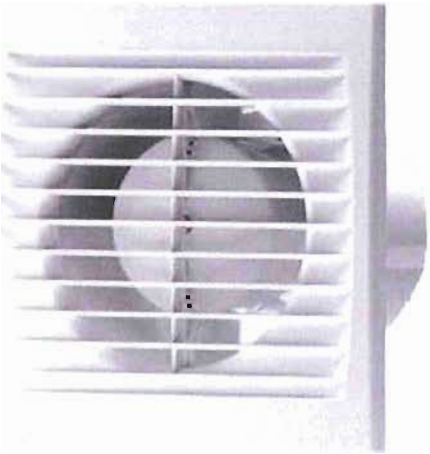


Technical Data				
Fan Speed	Avg. dBA	kWatts	Amps	Max. °C
22	41	0.04	0.25	

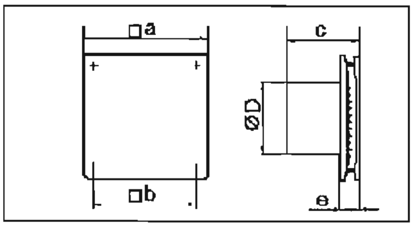
In-duct Sound Power Levels L_wdB re 1pW							
63	125	250	500	1k	2k	4k	8k

EN Series - EN20

S Series Wall / Ceiling Exhaust Fan



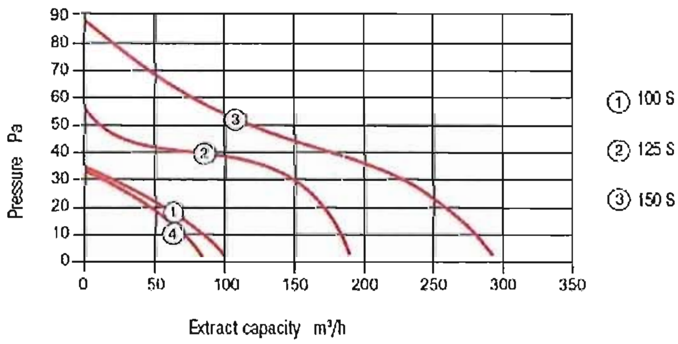
These series of fans can be used as ceiling or wall fans and can
be
connected to short lenghts of ducting.



DIMENSIONS (mm)						
Model	A	B	C	D	E	Kg
EMVUSS2	176	140	114	125	12	0,7.
EMVUSS3	205	165	132	150	13	0.9

Technical Details						
Model	m3/h	l/s	Pa	W	dB(A) @3m	protection
EMVUSS2	180	50	55	16	35	IP34
EMVUSS3	292	81	86	24	38	IP34

Performance Curves



Ring Plate Series - RP202

Location

Designation

Project

Notes

FEATURES

The Ring Plate Axial Fan, suitable for wall or ceiling mounting, is a high quality, cost effective fan suitable for a broad range of commercial and industrial applications.

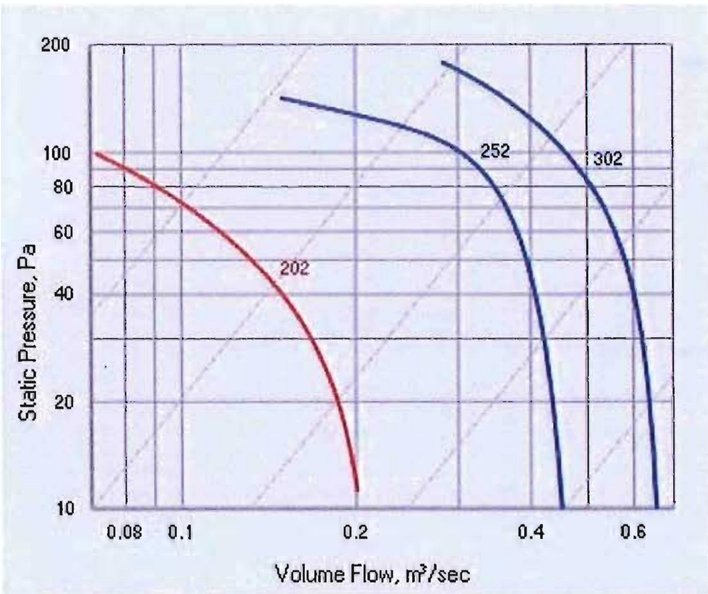
Construction
Ring Plate and Vogue fans have a galvanised steel fan impeller and ring. The fan impeller is black in colour, while other components have an Oyster Grey powder-coated finish.
Wiring access is from the rear: Vogue fans have a junction box.

Motors
Type - external rotor, squirrel cage induction motor.
Electricity supply - 220-240V, single-phase, 50/60Hz.
Bearings - sealed-for-life, ball.
Speed-controllable.
Motor protection IP44.
If flameproof motors are required, refer to Compact Flameproof Series - Square Plate Fans for full selection information.

Internal Thermal Protection
Auto-reset type fitted as standard on all sizes.

Testing
Air flow tests to ISO5801:2004.
Noise tests to BS848:Part 2, 1985.

Special Features
Reverse air flow can be provided; add the suffix 'R' to fan code and derate performance by approximately 20%.
Can be mounted at any angle.
Suitable for exhaust or supply through ductwork.



Technical Data

Fan Speed	Avg. dBA	kWatts	Amps	Max. °C
43	52	0.07	0.36	70

In-duct Sound Power Levels
L_WdB re 1pW

63	125	250	500	1k	2k	4k	8k
78	69	68	66	69	65	60	

Ring Plate Series - RP202

Appendix E – Recommendation from HSE Commissioned Report

The following is the Recommendation from Reference 19

a) *An additional 50cm² has been found to be inappropriate in many situations. Consequently, it is recommended that the guidance: 50cm² additional ventilation will generally be sufficient should be removed from both BS5440-2 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*

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.*