Health and Safety Executive

Domestic carbon monoxide alarms

Long-term reliability and use scoping study

Prepared by the **Health and Safety Laboratory**
for the Health and Safety Executive 2011

RR847
Research Report

HSE

Health and Safety Executive

Domestic carbon monoxide alarms

Long-term reliability and use scoping study

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Carbon monoxide (CO) is an invisible, odourless and tasteless gas produced in the home by any fuel-burning appliance. Properly installed appliances are designed to combust fuel efficiently and produce little waste CO; any CO that is produced is either vented from the room to outside by a flue or chimney, made inert by a catalytic converter associated with the appliance, or is left to disperse naturally.

CO alarms are widely recommended as one of a number of important measures to protect against the health risks associated with CO leaks from fuel burning appliances. The expected lifetime of CO alarms has been increasing since their introduction in the mid-1990s and some current models have an expected lifetime of more than 6 years under normal operation. This report seeks to derive evidence on the reliability and use of CO alarms currently employed in UK domestic settings, to support consumer advice regarding their effectiveness and usage.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the author alone and do not necessarily reflect HSE policy.

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First published 2011

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ACKNOWLEDGEMENTS

We acknowledge the assistance of Carbon Monoxide Awareness Ltd (Charity), Council of Gas Detection and Environmental Monitoring (CoGDEM) and Gas Safe Register in specifying the project; Gas Safe Register in collecting the CO alarms and administering the questionnaires; CoGDEM in providing new, replacement alarms; and the householders for agreeing to test their alarms.

KEY MESSAGES

Carbon Monoxide (CO) is an invisible, odourless and tasteless gas produced by any fuel-burning appliance. Properly installed appliances are designed to combust fuel efficiently and produce little waste CO. Audible CO alarms can be used to detect when CO reaches levels which may be hazardous. For this report, approximately 100 CO alarms, previously used by people in their homes, were tested and their use analysed. The key messages of this report are:

- Sensors in CO alarms don't last forever – check the manufacturer's quoted lifetime for your CO alarm and replace it no later than recommended to ensure you continue to have adequate protection.

- Before purchasing a CO alarm, always ensure it complies with British Standard EN 50291 and carries a British or European approval mark, such as a Kitemark. Standards for the performance of CO alarms have become more stringent over recent years and so older alarms may not react as quickly as newer alarms. Check the manufacturer's recommendations about how you can test your alarm to ensure that the unit and the batteries are in good condition.

- 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.

- 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. Carbon monoxide can be generated by any combustion fuel and so it is important that all appliances are installed and maintained by competent engineers. For gas appliances by law this should be a Gas Safe registered engineer, for solid fuel appliances the approved body is HETAS, and for oil appliances the approved body is OFTEC.

EXECUTIVE SUMMARY

Carbon monoxide (CO) is an invisible, odourless and tasteless gas produced in the home by any fuel-burning appliance. Properly installed appliances are designed to combust fuel efficiently and produce little waste CO; any CO that is produced is either vented from the room to outside by a flue or chimney, made inert by a catalytic converter associated with the appliance, or is left to disperse naturally.

CO alarms are widely recommended as one of a number of important measures to protect against the health risks associated with CO leaks from fuel appliances. The expected lifetime of CO alarms has been increasing since their introduction in the mid-1990s and some current models have an expected lifetime of more than 6 years under normal operation, leading to some manufacturers offering warranty periods of 5, 6 or even 7 years. However, concerns have been expressed as to the reliability of these alarms over an extended period. This report seeks to derive evidence on the reliability and use of CO alarms currently employed in UK domestic settings, to support consumer advice regarding their effectiveness and usage.

The objectives of the study reported here are:

1. To estimate the reliability of domestic CO alarms, which have been in normal service in consumers' homes, based on the 330 ppm CO test, for those certified to the British standard BS EN 50291, or the 400 ppm CO test, for those certified to the US standard UL 2034.

2. To derive information on the domestic use of CO alarms, from data obtained from householders by questionnaire, and relate such data to the recommendations contained in the guidance standard BS EN 50292.

3. To recommend good practice with regards to the effective use of domestic CO alarms in the UK.

A total of 110 households with a CO alarm installed in their home were recruited to the study. Each home was visited during which the alarm identified for testing was uninstalled, replaced with a new alarm, and a study questionnaire was administered. The questionnaire was administered by a Gas Safe Register Inspector and was designed to record specifics regarding the alarm and its use, including the alarm make and model, its age, where it was sited in the home, whether it was correctly sited, and how often it was tested. Other, more general information on the property was also collected, such as property type, tenure, and specifics regarding the fuel appliances present in the property.

Alarm reliability was assessed under laboratory conditions by testing conformity to one of two standards relating to performance of CO detectors deployed in domestic premises, either the British (European) standard, BS EN 50291 for UK certified models, or the US standard, UL 2034 for US certified models. The test methodology was agreed between HSE, HSL, Carbon Monoxide Awareness Ltd (Charity), Council of Gas Detection and Environmental Monitoring (CoGDEM) and Gas Safe Register, and involved initial push button testing, followed by sensor inclusive gas testing. With regards gas testing, alarms certified to BS EN 50291 were tested using the highest CO concentration (330 ppm) test specified in the standard; the standard requires activation of the alarm within 3 minutes following the initiation of exposure. Alarms certified to UL

2034 were tested using the equivalent high concentration (400 ppm) test specified in the standard; this standard requires activation of the alarm between 4 and 15 minutes following the initiation of exposure.

Effectively, two aspects of CO alarm use were investigated as part of this study: the reliability of alarm sensors to detect CO according to specific requirements set out in BS EN 50291 or UL 2034, and whether the alarms were appropriately used and deployed in homes by householders, e.g. according to BS EN 50292 guidelines. With regards to laboratory testing, alarms tested as part of the study were classed as “fails” for one of two reasons (or potentially both): (a) because they failed the initial button testing (9% of all alarms tested), either because batteries were simply absent or depleted (6%), or a more permanent sealed-battery or electronic failure (3%); or/and (b) because they failed subsequent gas testing (1% of alarms tested).

It is worth noting that two thirds (6/9) of the alarms failing initial button testing, failed simply because the batteries powering the alarms were depleted.

The percentage of households in the study reporting previous CO problems in their home was 6%; the profile of these households was mixed, including those in both owner occupied and rented properties, those with both open and balanced flue fuel appliances, and those in terraced, semi-detached and detached properties.

Consumers in this study who tested their CO alarms did so by using the push button, thereby essentially testing the electronics of the alarm. Products are, however, currently available for consumer use, which utilise CO gas to test the sensor of a CO alarm.

Variability in alarm age and failure rates in the alarms gas tested were both insufficiently high to allow reliability of alarms of greater than 2 years in age, along with factors potentially affecting alarm failure, to be investigated in detail. Based on the analyses that could be undertaken, the following inferences may be made:

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.

Standard BS EN 50292, offers guidance to consumers on how alarms should be deployed in the home to maximise their ability to detect abnormally high levels of CO. The home surveys carried out by Gas Safe Register Inspectors as part of this study highlighted that 23.6% of alarms were incorrectly deployed, the most common reason being that the alarms were inappropriately positioned in the room (e.g. wrong height from floor), the case for 76.0% of those incorrectly deployed; in 24.0% of cases, the alarms were identified as being not sufficiently close to potential sources of CO in the home.

The survey data suggested that alarms were significantly more likely to be incorrectly deployed when deployed in lounges (35.5%), compared to kitchens (9.8%). There was also some evidence suggesting that homeowners were more likely to deploy alarms incorrectly (26.3%), than landlords deploying alarms in rented properties on tenant’s behalf (20.0%), although the latter difference was not large. The latter may contribute to the observed tendency for incorrect deployment of alarms in lounges, given that homeowners appeared to prefer deploying their alarms in such a location. Considering HSE’s 2006 review of Gas Safety reported that CO poisoning related incidents most commonly involved poisonings in lounges and bedrooms, maximising the potential of alarms to detect CO leaks as early as possible in such rooms in particular is obviously critical.

Owners of properties appear generally more aware of the health risks of CO in homes, and appear more likely to frequently check that their alarms are working correctly. Given that home owners have responsibility for the control of CO risks in their homes, the merits of campaigns to raise awareness of further issues such as the importance of regular servicing of appliances, the benefit of installing a CO alarm, and the importance of their correct deployment, are likely to be greater.

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1 INTRODUCTION

Carbon monoxide (CO) is an invisible, odourless and tasteless gas, and is extremely toxic to humans[1]. CO is produced in the home by any fuel-burning appliance. Properly installed appliances are designed to combust fuel efficiently and produce little waste CO, any CO that is produced is either vented from the room to outside by a flue or chimney[a], made inert by a catalytic converter associated with the appliance[b], or is left to disperse naturally[c].

The risk of being exposed to CO in the home is principally determined by the presence of fuel burning appliances and aspects of their maintenance and use, the most important risk factor being the use of poorly serviced and poorly vented gas appliances. Waste emissions from vented fuel burning appliances (including those burning oil or solid fuels) may be vented to outside either by an open (or conventional) flue, closed (or balanced flue), or a chimneystack; alternatively, a fuel appliance may be flueless. With an open flue, the appliance draws combustion air from its surroundings; adequate ventilation to ensure that air can pass from outside to the room containing the appliance is therefore essential. The flue is engineered so that the waste gases of combustion are naturally drawn or “pulled” from the appliance through the flue. With a balanced flue, there is no exchange of air between the room and appliance; combustion air is supplied to the appliance from outside and the waste gases of combustion are vented to outside. Balanced flue appliances, particularly where venting is fan assisted, are therefore generally regarded to present a lower risk of CO exposure when compared to open flue appliances [2,3]. Consistent with this, HSE’s 2006 review of gas safety[3] reported the frequency of fatalities over the period 1996 to 2003, attributable to faulty appliances, to be highest for appliances fitted with open, individual, or natural draught flues.

Due to the potential risk of CO poisoning associated with domestic gas appliance use, the Gas Safety (Installation and Use) Regulations 1998 place restrictions on the installation of non-room sealed gas appliances, such as fires and boilers with open flues, in sleeping accommodation. Furthermore, landlords have a legal responsibility to ensure all gas appliances and flues present in the properties they rent, are maintained and checked for safety annually by a Gas Safe registered engineer. In addition, whilst not a legal requirement, the fitting of a British Standard (BS) approved CO alarm is strongly recommended by HSE[d].

CO alarms are now extensively used in the UK to help protect against CO poisoning. It is estimated that 6-7 million CO alarms are in use in the UK, with about 1.5 million sales per year[2]. The expected lifetime of CO alarms has been increasing since their introduction in the mid-1990s and some current models have a stated replacement period of more than 6 years under normal operation. However, concerns have been expressed as to the reliability of these alarms over an extended period. This report does not include CO alarms for use in an industrial environment, which are generally tested for functionality as part of industrial control measures.

Many CO alarms available in the UK are sold as being compliant with BS EN 50291[4], a standard pertaining to the reliability of CO alarms used in domestic premises. The

[a] *For example, a flued gas fire, gas or oil boiler, or solid fuel appliance*
[b] *For example, some flueless gas fires*
[c] *For example, in the case of a gas cooker or bottled gas fire*
[d] *http://www.hse.gov.uk/gas/domestic/co.htm*

related standard, BS EN 50292[5], provides guidance on alarm selection, maintenance and use. In addition, some alarms sold by US manufacturers in the UK, are certified to the US standard, UL 2034[6], rather than the British standard. The British standards recommend periodic testing of alarms to ensure continued reliability. One method for testing whether the alarm is functioning is the "button test", an electronic test, which tests the electronics of the alarm and to a limited extent the functionality of the CO sensor. This is not however sensor-inclusive testing (or gas testing) which involves the use of a test gas administered to the alarm while it is in operation in the domestic premise. In response to the potential limitations of button testing, sensor test kits are available involving the application of controlled amounts of CO gas. While the British Standard mentions testing, it does not specifically advocate sensor-inclusive gas testing. There are plans for the US NFPA 720 standard (used in the USA) for the installation of CO detection and warning equipment[7] to advocate periodic gas and sensitivity tests for those CO alarms installed in commercial premises and households, where there is a contracted installer and maintenance company.

The reliability of CO alarms in identifying potential hazardous levels of domestic CO exposure is dependent in part on how they are deployed in homes. Guidance is usually provided by the manufacturer based on BS EN 50292, which recommends that an alarm is fitted:

- 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.

The standard also recommends that an alarm is not fitted:

- in an enclosed space,
- where it can be obstructed,
- directly above a sink,
- next to a door, window, extractor fan, air vent or similar ventilation opening,
- where the temperature may drop below –5 ºC or exceed 40 ºC.

For homes with sources of CO in many rooms, the standard recommends that if deploying an alarm in each room is not possible then priority should be given to rooms containing flueless or open flued appliances that are used most frequently, and in the rooms where occupants spend most time.

Previous work on domestic CO alarm testing was carried out on behalf of HSE in 2001 and 2003[8,9]. A number of models, both brand new and in service, were repeat tested longitudinally, based on BS 7860:1996[10], the standard in existence at the time[e]. Subsequently, there have been developments in technology, although the principal detection method based on the electrochemical fuel cell[11] remains the same. In this

[e] *BS 7860:1996 was superseded by BS EN 50291 in 2001.*

previous work, failure rates of 33% were observed after 1 year, 24% after 2 years, and 40% after 3 years. The majority of failures were attributed to excessive loss in sensor sensitivity. The reports also highlighted the potential limitations of periodic button testing of alarms, as such tests were suggested to be unable to test the continued reliability of the alarm sensor to detect CO.

The performance of CO alarms has also been evaluated in the USA to US standard, UL 2034[f]. An assessment of the performance of newly purchased residential CO alarms carried out by the US Gas Research Institute[12], in 2002, tested conformance of 10 popular makes of alarm available in the US, to the UL 2034 specification. Performance of the different brands was found to be very variable; non-compliance with UL 2034 for sensitivity to CO was reported to be 47% in the worst 6 brands (at 50% relative humidity), compared to 0% in the top 3 brands; the combined failure rate was 25%. In addition, false alarms in the worst brands were reported in 8%, and alarming with interference gas in 30%. Failure rate at low humidity (5% relative humidity), in the worst 6 brands, was found to be even higher, at 79%.

HSE, in 2006, published the findings of an extensive review of arrangements for the promotion of domestic gas safety across the UK[3]. The review involved both desk-based research, together with direct engagement with an array of key stakeholders[g], the latter documenting views by a combination of stakeholder forums, one-to-one and telephone interviews, work groups, and self-administered questionnaires.

This review highlighted that whilst fatalities attributable to domestic CO poisoning had halved between 1998 and 2004, such mortality trends had not been paralleled by similar reductions in the number of reported incidents relating to CO, nor the number of non-fatal CO poisonings. In addition, it was suggested that domestic CO problems could be underestimated due to potential underreporting of cases.

Other findings highlighted in the review include observed evidence for a change in risk patterns with regard to CO poisoning. This was particularly in relation to the move from tenanted properties, where landlords have responsibilities to manage gas safety issues, to home ownership where the home owner is responsible for the control of CO risks in their homes. This change was deemed to have substantially increased the importance of and reliance on campaigns to increase awareness of the hazards of CO in domestic environments.

In investigations of specific trends in cases of CO poisoning, the prevalence of incidents was found[3] to be higher in owner occupied rather than rented accommodation, in terraced houses, and in lounges and bedrooms. Central heating gas boilers were found to consistently account for the majority of CO fatalities year on year, followed by space heaters (including gas fires), particularly those with open, individual or natural draught flues. The most common root cause was identified as lack of servicing of gas appliances and associated flues.

With regards to CO alarms specifically, the review[3] highlighted their increasingly important role in the raft of measures employed to reduce the risk of CO poisoning, which was attributed to their improved reliability and reduced cost over recent years. The importance of locating alarms correctly was emphasised as well as the periodic

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[f] *The 3rd edition (2008) of UL 2034 is the latest, but the test method and alarm settings have not changed since amendments to the 2nd edition (1996) in 2001.*

[g] *Represented groups including CORGI, gas installers, suppliers and inspectors, CO victim representative bodies, relevant training/assessment providers, central government, the Health and Safety Executive, devolved administrations (Wales and Scotland), local government and trade unions.*

testing of batteries. Other key recommendations included the phasing out of open-flued appliances, especially older boilers, identified as particularly high risk, and the promotion of the use of CO detection alarms, particularly among susceptible groups, such as the elderly and those reliant on benefits.

From the regulations, guidance and studies briefly reviewed above, it can be seen that CO alarms are advocated as one of a number of important measures to protect against the health risks associated with CO problems in the home. It is therefore important to derive evidence on the reliability of CO alarms currently employed in UK domestic settings, in order to advise on their effectiveness and usage. The objectives of the study reported here are:

1. To estimate the reliability of domestic CO alarms, which have been in normal service in consumers' homes, based on the 330 ppm CO test, for those certified to BS EN 50291, or the 400 ppm CO test, for those certified to UL 2034.

2. To derive information on the domestic use of CO alarms, from data obtained from householders by questionnaire, and relate such data to the recommendations contained in BS EN 50292.

3. To recommend good practice with regards to the effective use of domestic CO alarms in the UK.

2 IMPLICATIONS

This study aimed to investigate the reliability of CO alarms currently employed in UK domestic settings, in order to advise on their effectiveness and usage. A number of implications may be identified based on study findings, which is based, however, on a limited sample (approximately 100) of alarms:

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[9]. Such a finding supports the view that CO alarms have an important part to play in the measures to protect against the hazards of domestic CO exposure.

Alarms appear to be more frequently deployed correctly and replaced in rented properties, most probably by a tenant's landlord. Owners of properties appear generally more aware of the health risks of CO in homes, and appear more likely to frequently check that their alarms are working correctly. These subtle differences in behaviour suggest that occupiers of rented properties may particularly benefit from a raised awareness of the importance regular testing of their CO alarms, whereas homeowners may particularly benefit from a raised awareness of the importance of correct deployment and the need for periodic replacement.

Given that home-owners are responsible for the control of CO risks in their homes, the merits of campaigns to raise awareness of further issues such as the importance of regular servicing of appliances, the merits of installing CO alarms, and the importance of their correct deployment, are likely to be greater.

The percentage of households in this study reporting previous CO problems in their home was 6%; the profile of these households was mixed, including those in both owner occupied and rented properties, those with both open and balanced flue fuel appliances, and those in terraced, semi-detached and detached properties.

3 METHODOLOGY

3.1 INTRODUCTION

The methodology was agreed after meetings between HSE and HSL, Carbon Monoxide Awareness Ltd (Charity), Council of Gas Detection and Environmental Monitoring (CoGDEM) and Gas Safe Register. A primary objective of the study was to test alarms that had been in normal service in consumers’ homes for varying periods but within the manufacturer’s stated lifetime. It was decided that approximately one hundred alarms would be tested in this scoping study to gain an initial estimate of the failure rate. Also, it was attempted, as far as practicable, to reproduce in the sampled population the distribution of the different manufacturers’ alarms throughout the UK. Additionally, information on the carbon monoxide alarms identified for testing and their location, together with other information about their usage was gathered by questionnaire.

Suitable homes with CO alarms installed were identified by Gas Safe Register and invited to participate in the study. A convenient time for a Gas Safe Register inspector to visit was arranged with the occupier. During the visit, the alarm identified for testing was uninstalled, replaced with a new alarm (supplied by CoGDEM), and the questionnaire was administered. The uninstalled alarms were sealed in a protective bag (to prevent contamination by extraneous material and to prevent the alarm sounding inadvertently in transit) and sent by first class post to HSL Buxton. The alarms were removed, checked and then tested under laboratory conditions using the high CO concentration (300 ppm) test specified in the current British (European) standard (BS EN 50291:2001) for those alarms certified under this standard. The requirement is that the alarm should activate within 3 minutes. There are also alarms available in the UK that have been certified to the US standard (UL 2034). These were tested using the high CO concentration (400 ppm) test specified in this standard. The requirement is that the alarm should activate between 4 and 15 minutes. The pre-check and gas tests are described in more detail below.

3.2 QUESTIONNAIRE

The questionnaire was used to record information on the alarm and its location in the home. The factors covered were:

- Description of the CO alarm, including an estimate of its age
- Description of the location of the alarm, including a sketch if possible, and whether it was sited in accordance with BS EN 50292
- History and experience of use

The blank questionnaire template is shown in the Appendix (Section 6).

3.3 ALARM TESTS

3.3.1 General

Alarms received for testing were first subjected to the push button test (i.e. the test button on the alarm to check the electronics) to check whether a problem had developed in transit and whether the batteries were still functional. If the alarm passed this test then it was gas tested as detailed in Section 3.4. If it did not, then checks were carried out to see whether the batteries were fitted properly and working. If this was capable of being rectified then the gas test was performed. If it was not possible to rectify the problem, then the alarm was not gas tested and not counted as a gas test failure but recorded as a ‘non-test’.

Each alarm was numbered and photographed and all values of the measured parameters derived from each test were recorded on a form.

The digital readout from those alarms having this feature was compared with the reference CO concentration in the test chamber.

3.4 TEST PROCEDURES

3.4.1 BS EN 50291

For alarms certified to BS EN 50291, the 300 ppm set point test as described in the standard was performed. The test gas volume ratio used in this test is specified as 330 ± 30 ppm CO in air. In order to pass the test the alarm should activate within 3 min. In addition, recovery from the alarm state was tested – the alarm should recover its clean air (zero) reading after manual resetting if necessary, within 6 min when exposed to clean air. See Appendix for details.

The time to alarm was calculated by measuring the time taken for the alarm to sound after the CO concentration had reached the specified lower limit i.e. 300 ppm.

3.4.2 UL 2034

For alarms certified to UL 2034, the 400 ppm CO in air test as described in the standard was performed. See Appendix for details.

3.4.3 General

The time to alarm was calculated by measuring the time taken for the alarm to sound after the CO concentration had reached the specified lower limit (i.e. 300 and 390 ppm for the BS EN and UL tests respectively) for each test as described above.

Each alarm was numbered and photographed and all values of the measured parameters derived from each test (see Appendix) were recorded on a form.

3.5 DATA ANALYSIS

A study database was established for the recording of both gas test and questionnaire collected data. The blank database was populated by a series of fields relating to the individual pieces of data collected. Prior to the commencement of data entry, for those questions with a pre-defined set of answers, all possible answers to questions were assigned a numerical code. A written protocol was then developed based on such coding for use as a guide by the members of the study team tasked with data entry. All data was then entered into the database in preparation for analysis. Following data entry, quality checks were carried out on a sub sample of the data entered, to mitigate against data entry errors. Analysis of the study dataset was carried out using SPSS v14.0 for Windows.

All data was first descriptively summarised in order to provide key descriptive statistics for inclusion in the study report and to guide subsequent analysis. Owing to the limited size of the study dataset, the analytic methods carried out were limited to univariate tests of association and univariate regression. The dataset, in the main, consisted of categorical variables, the key outcome variable of interest being gas test result (i.e. pass or fail). Associations between gas test result and a range of putative risk factors, including alarm manufacturer, alarm exposure history and alarm age, were investigated, in the main, by testing for significant differences in number of gas test failures across pertinent categories and calculating gas test failure odds ratios. The latter were calculated by deriving values of the ratio of the odds of gas test fails (i.e. the ratio of numbers of fails to passes) in the categories of interest (e.g. in homes with smokers), expressed relative to a suitable reference category (e.g. homes without smokers). It follows that odds ratios close to unity (i.e. to a value 1.00) indicate little difference in gas test failure rates in the categories being compared; conversely, ratios greater than 1.00 indicate failure rates in the category of interest higher than the reference category; while ratios less than 1.00 indicate failure rates in the category of interest lower than the reference category. The statistical significance of any deviation from unity was assessed by the calculation of 95% confidence limits for each odds ratio.

Two-by-two cross tabulations of categorical data were analysed via calculation of Mantel Haenszel common odds ratios and associated approximate 95% confidence limits, and 2-by->2 and >2-by->2 cross tabulations via Chi Square Tests and derivation of associated approximate significance levels. In addition, owing to several cell counts being less than 5, association between gas test result and factors of interest were also investigated by computing exact significance levels by employing exact tests. P-values less than 0.05 were taken to indicate a statistically significant association/difference.

The association between gas test result and alarm age was investigated in analyses by treating alarm age as a continuous variable. Tests of normality showed alarm age to be non-normally distributed therefore its association with gas test result was initially investigated using the non-parametric Mann-Whitney U Test. Association between the two variables was also modelled via Logistic Regression, allowing inferences to be made regarding expected gas test failure rates for alarm ages too poorly described by the study dataset, which would have been difficult because of the limited study data available.

4 RESULTS

4.1 VISITS

Gas Safe Register Inspectors visited 107 homes as part of this study, and 110 CO alarms were collected and sent to HSL for gas testing, along with 107 completed questionnaires detailing supporting information collected from householders.

4.2 PROFILE OF CO ALARMS TESTED

A number of alarms sent to HSL for testing were subsequently found to be accredited to BS 7860:1996 (the standard predating the current BS 50291:2001 standard), or were older than the manufacturer's recommended lifespan; these were omitted from testing[h]. Test results are reported for the remaining 100 alarms. The final dataset was made up of alarms from 7 different manufacturers (4 UK manufacturers and 3 US), with 17 different alarm models represented. The numbers of different makes and models of CO alarms for which testing was carried out, are provided in Tables 1 and 2.

Table 1 – Descriptive Summary of Study Dataset – Alarm Makes Tested

	Category	*N**	*Counts across categories*	*% across categories*
Alarm Make		100		
	A		58	58.0
	B		21	21.0
	C		9	9.0
	D		7	7.0
	E**		5	5.0

*N = Total number of alarms in study sample; **American manufacturers combined (3 in total)

Table 2 – Descriptive Summary of Dataset – Alarm Makes and Models Tested

	Category	*N*	*Counts across categories*	*% across categories*
Alarm Make and Model		100		
	A1		1	1.0
	A2		24	24.0
	A3		26	26.0
	A4		1	1.0
	A5		6	6.0
	B1		20	20.0
	B2		1	1.0
	C1		2	2.0
	C2		1	1.0
	C3		1	1.0
	C4		5	5.0
	D1		5	5.0
	D2		2	2.0
	E1		1	1.0
	E2		2	2.0
	E3		1	1.0
	E4		1	1.0

N = Total number of alarms in study sample

[h] The test conditions in BS 7860:1996 are less stringent than those in BS EN 50291:2001; the gas concentration test in BS 7860 requires the alarm to activate within 6 min upon exposure to 350 ppm.

The age profile of alarms tested is summarised in Table 3. The median age of alarms tested was 2.0 years; 40% were less than two years old, 59% between 2 and 6 years and 1% greater than 6 years.

Table 3 – Age Profile of Alarms Gas Tested

Factor	*Category*	*N**	*Counts across categories*	*% across categories*
Alarm Age		93		
	0 to 1.9 years		37	39.8
	2 to 5.9 years		55	59.1
	6+ years		1	1.1

*N = Total number of alarms in study sample with data

4.3 TEST RESULTS

It was found that of the 100 alarms tested, 9 failed the initial button test; 6 had new batteries fitted and subsequently passed the button test; the remaining 3 had sealed battery compartments, therefore it was not possible to replace the batteries and so gas testing was aborted. Gas testing was carried out on the remaining 97 alarms that passed a button test. The results of gas testing are summarised in Tables 4 to 6. The overall gas test failure rate for all alarms tested was 1/97 (1%). The failure rate for UK certified alarms only was 1/92 (1%), and 0/5 for US certified alarms. The one alarm failing gas testing was 2 years old.

Table 4 - Laboratory Gas Testing Summary Statistics – Tested According to BS EN 50291

Alarm Make/Model	*N*	*Passes*	*Gas test failures*	*Pre-test failures*	*Gas Test Failure Rate (%)*
A1	1	1	0	0	
A2	24	24	0	0	
A3	26	23	1	2	
A4	6	5	0	1	
A5	1	1	0	0	
B1	20	20	0	0	
B2	1	1	0	0	
C1	2	2	0	0	
C2	1	1	0	0	
C3	1	1	0	0	
C4	5	5	0	0	
D1	5	5	0	0	
D2	2	2	0	0	
All BS alarms	95	91	1	3	1.1

Table 5 - Laboratory Gas Testing Summary Statistics – Tested According to UL 2034

Alarm Make/Model	***N***	***Passes***	***Gas test failures***	***Pre-test failures***	***Gas Test Failure Rate (%)***
E1	1	1	0	0	
E2	2	2	0	0	
E3	1	1	0	0	
E4	1	1	0	0	
All UL alarms	5	5	0	0	0.0

Table 6 - Laboratory Gas Testing Summary Statistics – All Alarms Tested

	N	***Passes***	***Gas test failures***	***Pre-test failures***	***Gas Test Failure Rate (%)***
All alarms (BS and UL)	100	96	1	3	1.0

A summary of the testing carried out on the alarms making up the study sample and associated results is provided in Figure 1 below. 10/100 alarms (10%) failed either the initial button or gas test.

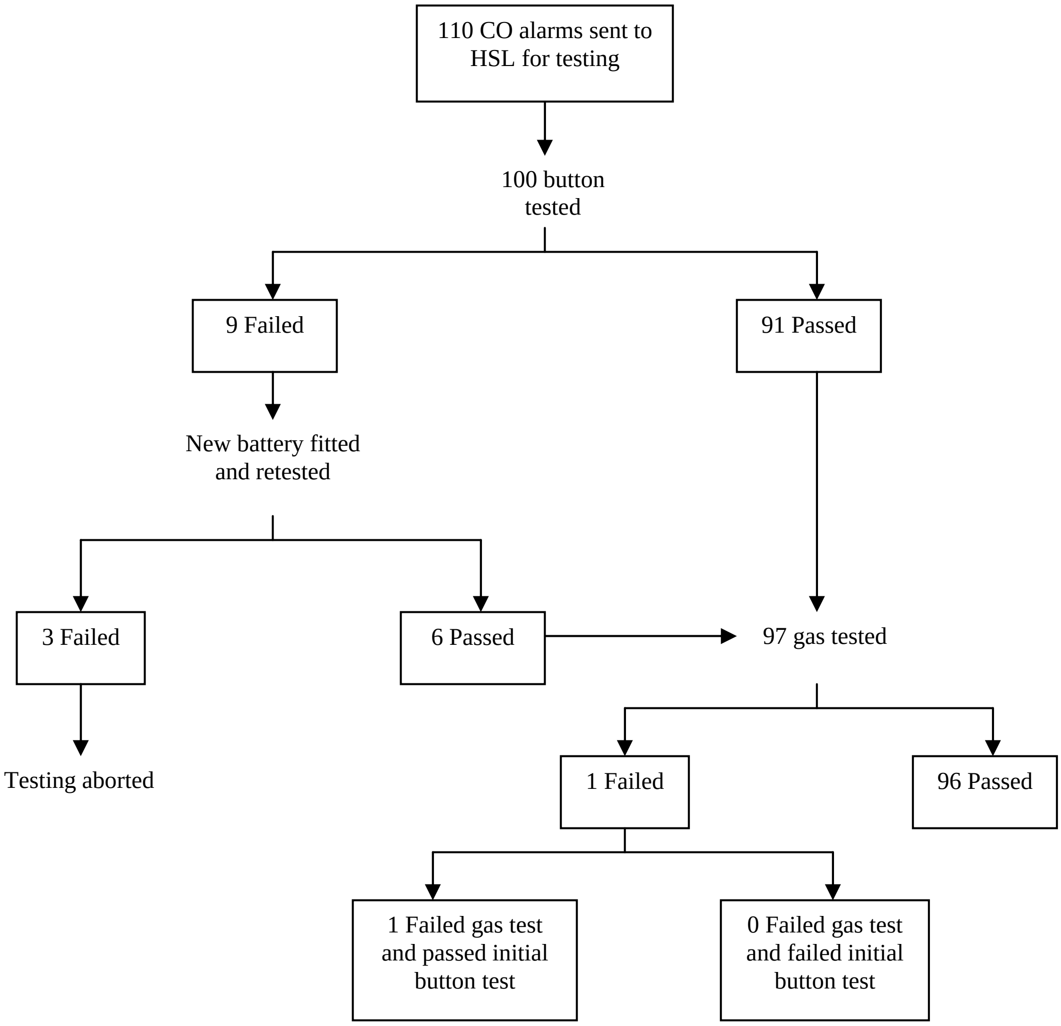

Figure 1: Summary of button and gas testing results

A complete breakdown of the initial button and gas test results is provided in Table 7.

Table 7 – Summary of button and gas testing and results

	Gas test		***Failed button retest***	***Totals***	***Passed button retest***
	Passed	Failed			
Initial button test					
Passed	90	1	-	91	-
Failed	6	0	3	9	6
Totals	96	1	3	100	

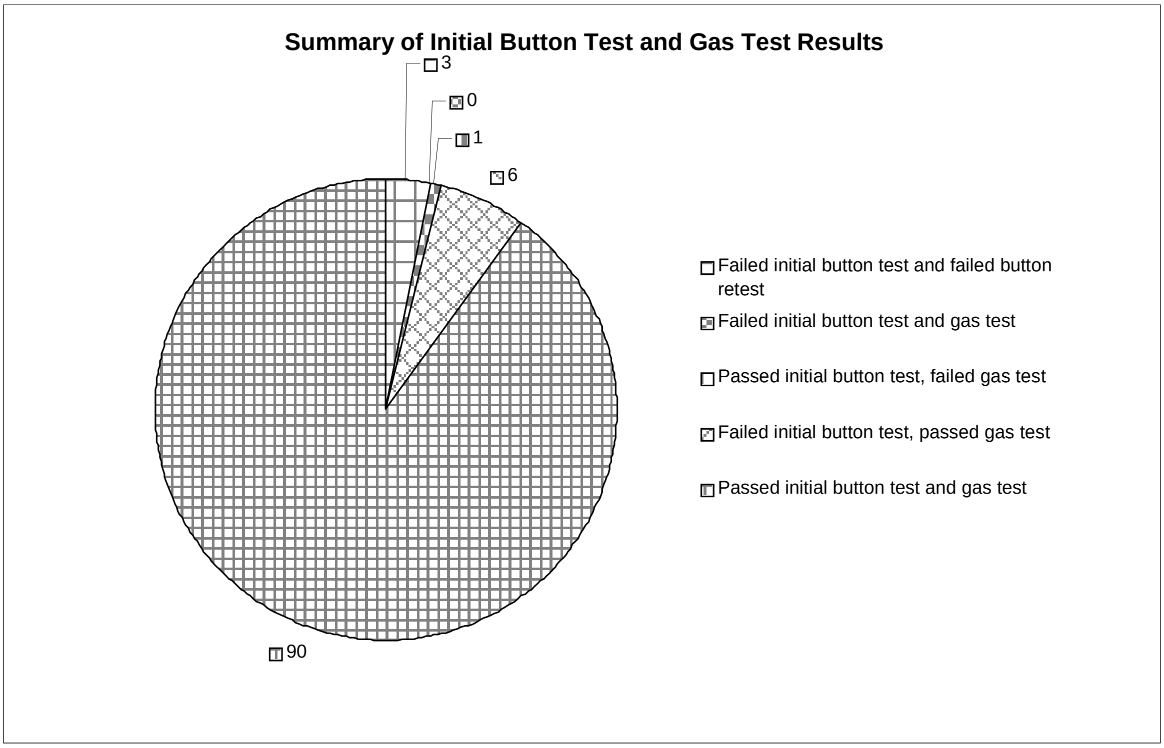

Figure 2: Summary of initial button test and gas test results

Some alarms now additionally provide a digital display of the CO concentration. In addition to continuously displaying the CO concentration (in ppm units), it also provides an identification of lower concentrations of CO than the lowest alarm level specified in BS EN 50291 (50 ppm). Such information may be of use to householders, especially vulnerable or at-risk groups. Three alarms received had this facility, however, a comparison was only made between the digital display and the reference CO concentration in the test chamber when the concentration reached its final steady-state value, i.e. around 330 ppm. The results are shown in Table 8.

Table 8 – Accuracy of alarm digital readout

Actual CO concentration at steady-state (ppm)	***Alarm digital readout at steady-state (ppm)***	***% error***
328	267	-18.6
331	470	+42.0
330	220	-33.3

It can be seen that these alarms under-read or over-read the CO concentration around 330 ppm by between -33 and +42%. This data suggests the readout is suitable as a semi-quantitative indication of the CO concentration or as an indication of low concentration CO exposure below the alarm threshold, although measurement of the accuracy of such alarms at these levels was outside the scope of this work.

4.4 PROFILE OF HOUSES/HOUSEHOLDS SURVEYED

Detailed summary statistics on the houses from which alarms were obtained for testing are shown in Table 9. Approximately 66% of the properties were rented properties and 33% owner occupied; around 33% were flats, 25% semi-detached and bungalows, and just over 10% terraced and detached properties. Just over 40% of alarms collected for testing were originally deployed in the kitchen, around 30% in the lounge, and the remaining 25% in the hallway, landing or a bedroom. Table 9 also provides a summary of the fuel appliances present in the properties surveyed. The majority (98%) of properties had at least one gas appliance; approximately two thirds had a gas appliance with a balanced flue, nearly half an appliance with an open flue, and around a third a flueless gas appliance, typically a gas cooker.

Table 9 – Summary Statistics – Characteristics of Houses Surveyed

Factor	***Category***	***N***	***Counts across categories***	***% across categories***
House Type		106		
	Flat		31	29.2
	Bungalow		22	20.8
	Terraced		14	13.2
	Semi-detached		26	24.5
	Detached		13	12.3
House Tenure		106		
	Owner		39	36.8
	Rented		67	63.2
Location of Alarm		104		
	Bedroom		4	3.8
	Landing		9	8.7
	Hallway		16	15.4
	Lounge		31	29.8
	Kitchen		43	41.3
	Garage		1	1.0
Fuel Appliances				
	Gas fuel appliances in home?	91		
	None		2	1.9
	Balanced flue only		29	27.1
	Flueless only		4	3.7
	Open flue only		31	29.0
	Flueless and balanced		23	21.5
	Flueless and open		2	1.9
	Balanced and open		7	6.5
	Open, balanced and flueless		9	8.4
	Other fuel appliances in home?	107		
	None		105	98.0
	Solid fuel		1	1.0
	Oil		1	1.0

N = Total number of alarms in study sample with data

4.4.1 Issues regarding alarm selection, installation, deployment and testing

Only 25% of householders in the study sample reported being directly involved in choosing the model of CO alarm present in the home, attributable, in the main, to the predominance of rental properties in the sample and resultantly, the tenants landlord deciding which model of CO alarm to deploy and where to locate it (the case in 33%). In addition, around 20% of householders reported taking advantage of an offer for a free alarm. Of those that did have a say in the choice of CO alarm, around 33% reported that conformity of the model to BS EN 50291 was an influencing factor in their choice. Around 20% of householders reported that their choice to deploy a CO alarm in their home was driven by an awareness of the health risks of CO exposure. Around 73% of householders reported periodically testing their alarm via the test button. However, of these, only around 10% tested their alarm weekly or fortnightly, as typically recommended by alarm manufacturers, the majority (~90%) testing their alarm at best monthly/quarterly or 6-monthly; 37% reported only testing their alarm on an annual basis. A summary of data is provided in Tables 10 and 11.

Table 10 – Summary Statistics – Issues Regarding Alarm Selection/Installation

Factor	*Category*	*N*	*Counts across categories*	*% across categories*
Selection of alarm		100		
	Householder involved in selection of alarm?			
	Yes		26	26.0
	If yes:			
	BS a consideration?			
	Yes	24	8	33.3
	Reasons for installing alarm?	93		
	Third party recommendation		7	7.5
	Own awareness of issue		20	21.5
	Alarm free of charge		18	19.4
	Landlord policy		31	33.3
	Open flue appliance/back boiler		12	12.9
	Other/not known		5	17.2

N = Total number of alarms in study sample with data

Table 11 – Summary Statistics – Specifics Regarding Alarm Deployment and Periodic Testing

Factor	*Category*	*N*	*Counts across categories*	*% across categories*
Deployment of alarm		106		
	According to BS EN 50292 criteria?			
	No		25	23.6
	If no:			
	Reason why not?	25		
	Not sufficiently close to fuel appliance		6	24.0
	Incorrectly positioned in room		19	76.0
Alarm Testing		107		
	Alarm periodically tested via push button?			
	Yes		78	72.9
	If yes:			
	Frequency?	38		
	Once per year		14	36.8
	Monthly, quarterly or 6-monthly		19	50.0
	Weekly or fortnightly		5	13.2

N = Total number of alarms in study sample with data

Table 11 also summarises the number of alarms deployed according to the recommendations of BS EN 50292. Approximately 75% of alarms were appropriately deployed based on the opinion of the Gas Safe Register Inspector undertaking the house surveys. Of the 25% that were not, the most common reason was incorrect positioning within the room concerned (76%). Around a quarter (24%) of those inappropriately deployed were failed by the Gas Safe Register Inspector because of the alarm's distant location relative to potential sources of CO. Alarms deployed in the lounge were significantly more likely to be mis-positioned than those deployed in the kitchen, landing, hall or bedroom (see Table 12). There was also some evidence suggesting that homeowners were more likely to deploy alarms incorrectly (26.3%), than landlords deploying alarms in rented properties on tenant's behalf (20.0), although the latter difference was not large (see Table 16).

Table 12 – Association Between Alarm Location and Correct Alarm Deployment

Correct Deployment – *Alarm Location:*	*Yes*	*No*	*No %*	*Not sufficiently close to fuel appliance*	*Incorrectly positioned in room*
Lounge	20	11	35.5	2 (18.2)	9 (81.8)
Kitchen**	37	4	9.8	1 (25.0)	3 (75.0)
Other*	21	9	30.0	3 (33.3)	6 (66.7)

Test for association between alarm location and correct deployment
Chi-Square (Exact Sig)
P=0.02

*Bedroom, landing or hall

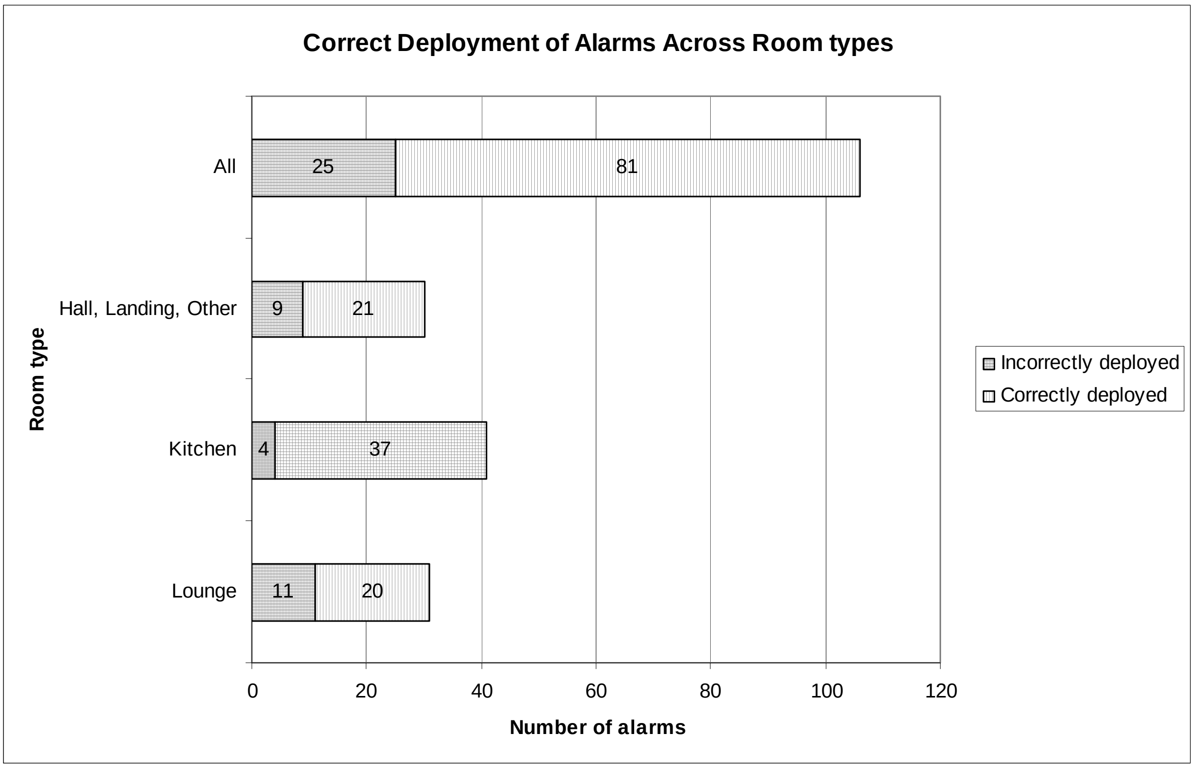

Figure 3: Correct deployment of alarms across room types

The prevalence of a history of domestic CO problems was explored by questioning as well as enquiry into whether the CO alarm tested had ever triggered. Few (6%) householders reported a history of CO problems in their property, while a similar percentage reported that their alarm had triggered in the past; 3% of householders reported positively to both questions. A summary of data is provided in Table 13.

Table 13 – Summary Statistics – Triggering History and Related Issues

Factor	*Category*	*N*	*Counts across categories*	*% across categories*
CO Problems		73		
	History of CO problems in home?			
	Yes		4	5.5
Triggering		109		
	Alarm ever triggered?			
	Yes		7	6.4

N = Total number of alarms in study sample with data

No statistically significant association was found between CO problems and the presence of particular types of gas appliances in the home, nor the previous triggering of an alarm and reported smoking of cigarettes in the room where the alarm was deployed (see Tables 14 and 15).

Table 14 – Association Between Fuel Appliances in Home and Reported History of CO problems

History of CO problems* – ***Fuel Appliances:***	*Yes*	*No*	*Yes %*
None	0	2	0.0
Balanced flue only	2	12	14.3
Flueless only	0	1	0.0
Balanced flue and flueless only	3	17	15.0
Open flue	4	34	10.5

Test for association between fuel appliances in home and CO problems
Chi-Square (Exact Sig)
P=0.867

*Positive cases taken as any households either reporting a history of CO problems in home or that CO alarm had triggered in past

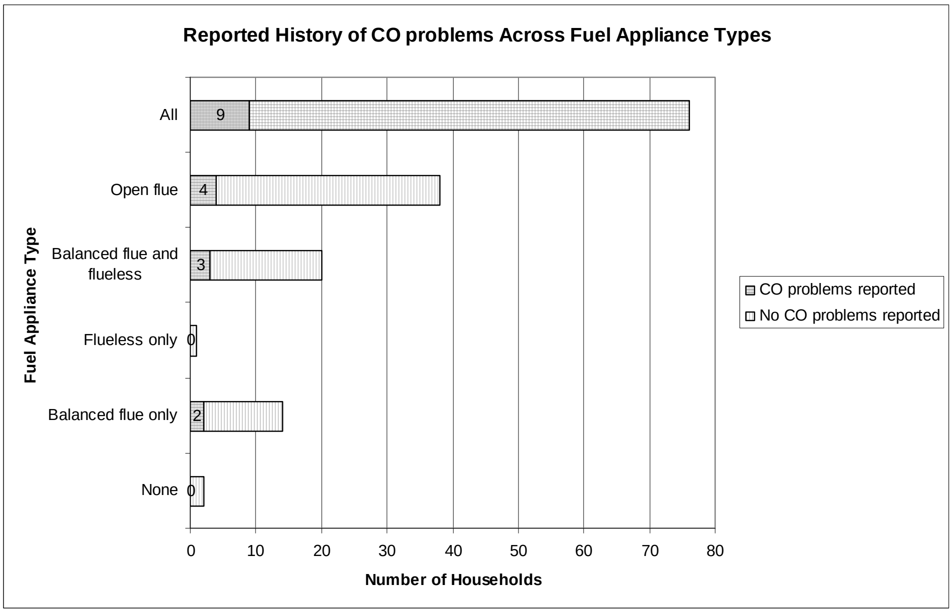

Figure 4: Reported history of CO problems across fuel appliance types

Table 15 – Association Between Reported Smoking in Room with Alarm Triggering

Alarm Triggering – ***Reported Smoking:***	***Yes***	***No***	***Yes %***
Yes	2	11	15.4
No	5	71	6.6

Test for association between smoking and alarm triggering
Chi-Square (Exact Sig)
P=0.270

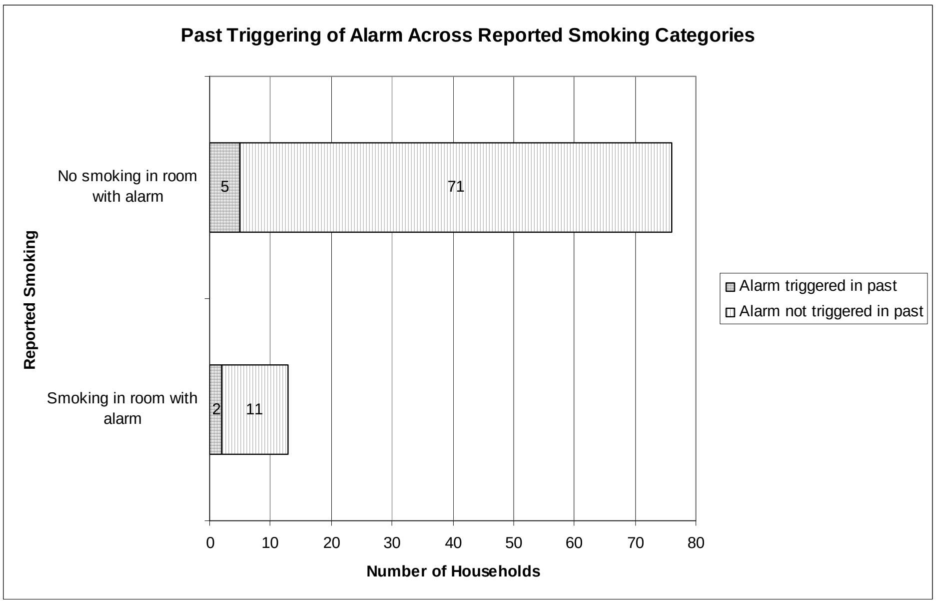

Figure 5: Past triggering of alarm across reported smoking categories

How the profile of potentially pertinent risk factors for alarm failure, and associated factors, varied with house tenure within the study dataset was also explored; factors are compared in Table 16. Significant differences across categories (P<0.05) were observed for alarm age, alarm location (house and room type) and frequency of alarm testing.

Table 16 – Association Between Various Factors and House Tenure

Factor	*Category*	*Owned property N=39 Count (%)*	*Rented property N=67 Count (%)*	*P Value**
Alarm age				0.017
	Mean age (years)	2.83	1.88	
House type				<0.001
	Flat	0 (0.0)	30 (46.2)	
	Bungalow	10 (25.6)	12 (18.5)	
	Terraced	4 (10.3)	10 (15.4)	
	Semi-detached	12 (30.8)	13 (20.0)	
	Detached	13 (33.3)	0 (0.0)	
Smoking habits				0.279
	Smoking in room with alarm?			
	Yes	4 (10.8)	14 (21.2)	
Gas appliances in home				0.553
	None	1 (2.6)	1 (1.5)	
	Balanced flue only	10 (25.6)	19 (28.4)	
	Flueless only	3 (7.7)	1 (1.5)	
	Balanced flue and flueless only	9 (23.1)	14 (20.9)	
	Open flue	16 (41.0)	32 (47.8)	
Alarm location				
	Room with alarm?			0.035
	Lounge	16 (42.1)	15 (23.4)	
	Kitchen	10 (26.3)	33 (51.6)	
	Other room	12 (31.6)	16 (25.0)	
	Deployed according to BS EN 50292?			0.458
	No	10 (26.3)	13 (20.0)	
Alarm installation				
	Reasons for installing alarm?			<0.001
	3rd party recommendation	7 (19.4)	0 (0.0)	
	Own awareness of issue	15 (41.7)	4 (7.4)	
	Alarm free of charge	11 (30.6)	7 (13.0)	
	Landlord policy	0 (0.0)	29 (53.7)	
	Other	3 (8.3)	14 (25.9)	
Alarm testing				
	Alarm tested periodically via push button?			0.275
	Yes	25 (65.8)	50 (75.6)	
	If yes: Frequency?			<0.001
	Once per year	0 (0.0)	13 (76.5)	
	Monthly, quarterly or 6-monthly	16 (84.2)	2 (11.8)	
	Weekly or fortnightly	3 (15.8)	2 (11.8)	

*Associated with test for significant difference across owner occupied and rented properties (alarm age tested via Mann Whitney U Test; other factors by Chi Square Test)

The mean age of alarms in owner occupied properties was 2.8 years, compared to 1.9 years in rented properties. In addition, alarms in owner occupied properties were more likely to be deployed in lounges and tested more frequently (monthly, quarterly or 6-monthly), relative to those in rented properties, which were more likely to be deployed in kitchens and tested only annually.

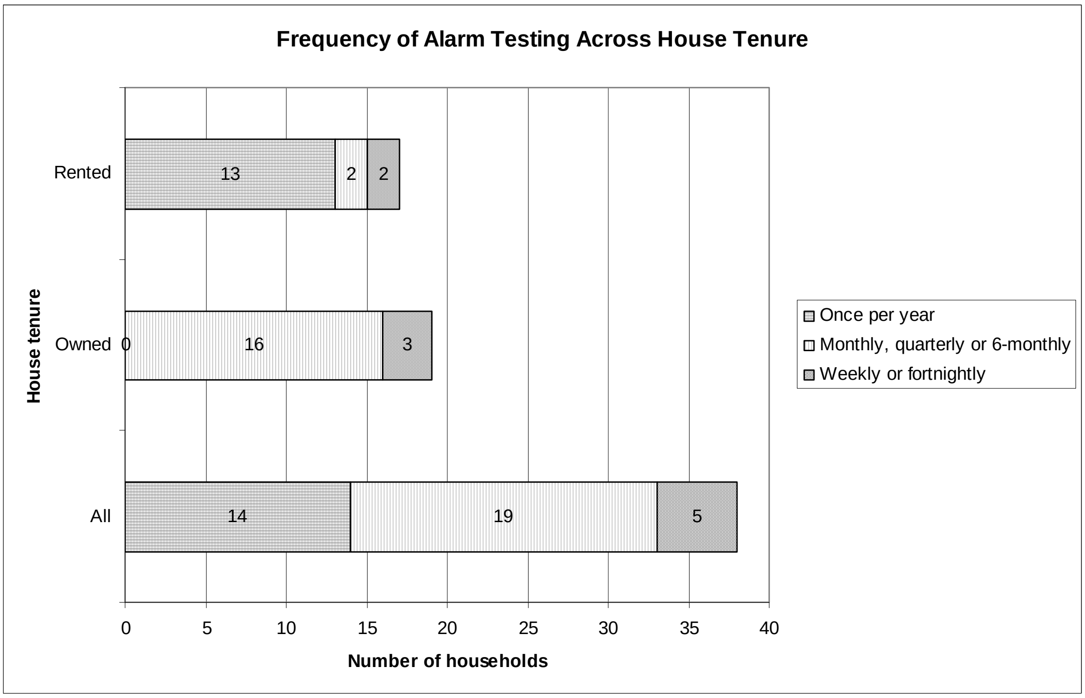

Figure 6: Frequency of alarm testing across house tenure categories

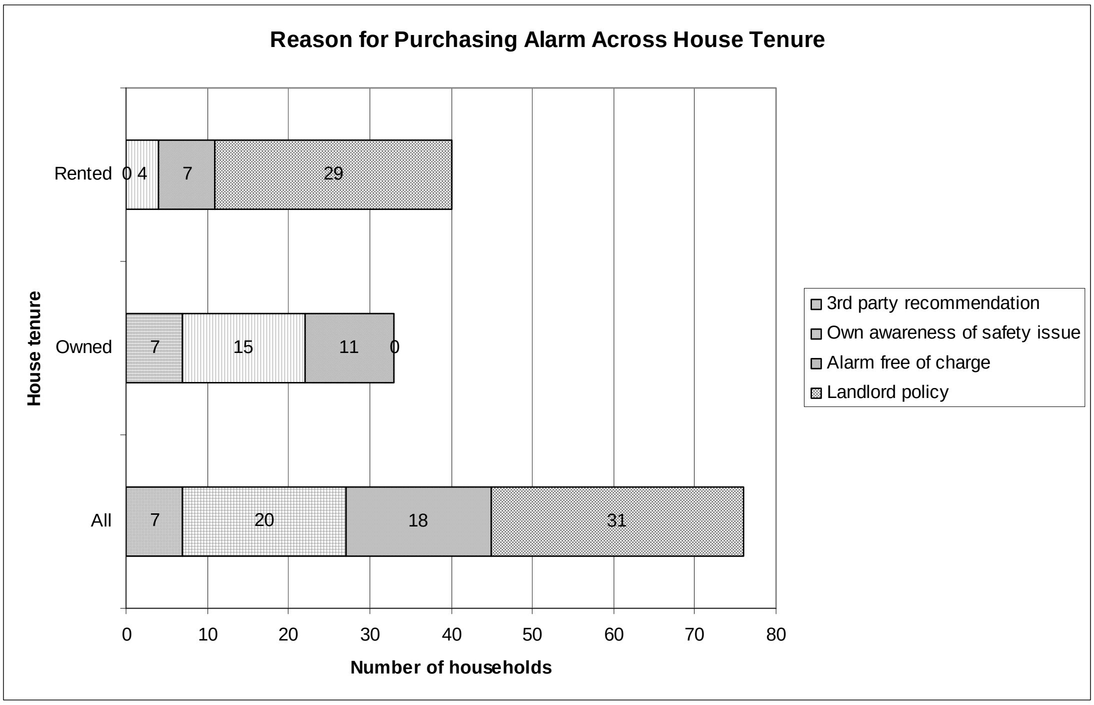

Figure 7: Reason for purchasing alarm across house tenure categories

4.5 DISCUSSION OF RESULTS

The primary aims of this study were to investigate the reliability and use of a sample of CO alarms, broadly representative of the makes and models of alarms commonly purchased by UK consumers, currently deployed in a representative sample of UK homes. To this end, a sample of households were recruited to the study in which the decision to deploy a CO alarm in their home had already been taken. Specifics regarding alarm deployment and use, for example, where in the house it was located and how often it was tested, and issues potentially affecting alarm reliability, such as proxies of the alarm's exposure history, were collected by questionnaire, along with information on factors that affected the householder's decision to purchase the alarm. The study data subsequently collected on these factors is regarded to provide a fairly representative snapshot for UK consumers generally, including those residing in both owner occupied and rented properties. Data on the UK market share of alarm manufacturers making up the study sample are shown in Table 17.

Table 17 – UK market share of alarm manufacturers represented in study sample

% Market share (ex CoGDEM)	*In study sample (%)*
25	54
15	24
15	10
20	7
25	5

The prevalence statistics calculated from the study data for factors such as the types of fuel appliances in the home, general awareness of the health risks associated with CO in domestic settings, and the reported prevalence of CO problems, will inevitably be affected somewhat by the fact the study sample was made up of households who already had an alarm installed in their home. The latter factor is likely to contribute to the relatively high proportion of rented properties making up the study dataset, as it is now common practice for landlords to install CO alarms in the properties they rent. Resultantly, the prevalence of rented properties with an alarm installed is likely to be somewhat higher at present than the equivalent figure for owner occupied properties. Current estimates suggest that approximately 1 in 5 of all UK homes have a CO alarm installed[2]. The bias towards rented properties in the study sample is likely to impact on how broadly representative other prevalence estimates are in the data.

The manufacturers of all UK certified models tested, claimed conformity to the British Standard BS EN 50291; all alarms tested employed electrochemical sensor technology. An overall summary of headline alarm failure rates are as follows: 9.0% (9/100) of alarms in the study sample failed initial button testing. It is worth noting, however, in two thirds (6/9) of cases this was because of the batteries powering the alarms were absent or depleted.

The results of a longitudinal field trial of CO alarm reliability, carried out by Advantica for HSE, reported in 2003[9], in which a broadly comparable profile of alarm manufacturers were tested to this study, observed annualised gas test failure rates of 33% after 1 year, 24% after 2 years, and 40% after 3 years. In addition, a 2002 study carried out in the US by the Gas Research Institute on newly purchased alarms sold for domestic use, reported a headline failure rate of 25%[12]. Comparing these figures to the equivalent headline failure rate observed in this study, suggests that significant improvements in alarm reliability have been made over the last 7 years. It is worth noting that the gas tests undertaken in the Advantica study quoted above were based on BS 7860 and included the 350 ppm CO test, where the requirement was for the alarm to sound within 6 min. In addition, both electrochemical and semiconductor sensors were tested, as both type of models were prevalent at the time. Therefore, while the results in the two studies are not directly comparable, they do nevertheless support the view that significant improvements in alarm technology have been made.

The gas test performed in the study reported here was the highest CO concentration test in BS EN 50291 (300 ppm alarm level test). There are additional tests specified for certification to BS EN 50291 which require alarms to activate at lower CO concentrations but over longer periods, e.g. for the 100 ppm level, the alarm should activate between 10 and 40 min, and for the 50 ppm level it should activate between 60 and 90 min. It is not known whether the failure rate for these tests on the sample of alarms would be different to the rate for the high concentration test.

The average manufacturer recommended lifespan of the alarms tested in this study is around 6 years. The median age of alarms tested was 2.0 years, while only 1% were 6+ years, highlighting that the majority of alarms deployed in the homes participating in the study were within the manufacturer's recommended lifespan. The number of alarms in the study sample that failed the initial button test (9/100, 9.0%) highlights the importance of regular button testing to identify alarms that are not working correctly. Alarm manufacturers typically recommend weekly testing of alarm electronics via the push button. Whilst the majority of householders (73%) reported periodic button testing of their alarm, only 13% reported weekly or fortnightly testing as recommended by manufacturers, 50% testing monthly, quarterly or 6-monthly, and 37% testing only annually. Testing of alarms in rented properties was particularly poor, with 77% testing only annually.

Landlords have a legal duty to ensure the fuel appliances and associated flues in the properties they rent are maintained in a safe condition to prevent the risk of injury to any person, e.g. from CO exposure. The deployment of CO alarms provides an additional measure to further mitigate against risk and therefore it is perhaps not surprising that a high proportion of tenants in rental properties reported the decision to install a CO alarm was made by their landlord, rather than themselves. In addition, the fact that the age of alarms was less in those deployed in rented compared to owner occupied properties, suggests that owners of properties may replace their alarms less frequently than tenants in rented properties (or their landlords). However, whilst property owners appeared to replace alarms less frequently, they were significantly more likely to attribute ownership of their alarm to a general awareness of the health and safety risks associated with domestic CO exposure (42%), than those living in rental properties (7%); as stated prior, the latter were more likely to attribute ownership of their alarm to their landlord (59%).

HSE's 2006 review of gas safety[3] suggested that the risk of CO problems in homes had gradually shifted away from rented properties and towards owner occupied properties, a trend which could be attributable to the duty of care imposed on landlords to control risk by the Gas Safety (Installation and Use) Regulations 1998. Whilst such a trend is not doubted, evidence from the data collected in this study suggests that the risks of CO problems in rented properties might be further reduced by raising awareness of the health risks of CO specifically among the occupiers of rented properties (as opposed to landlords themselves). In particular, awareness of issues such as the types of fuel appliances where the risk of CO related problems are higher, the signs to look for indicating CO might be being produced[i], and the importance of regular CO alarm checking. Given that home owners are responsible for the control of CO risks in their homes, the merits of campaigns to raise awareness of further issues such as the importance of regular servicing of appliances, the merits of installing CO alarms, and the importance of their correct deployment, are likely to be greater.

The risk of pollution of the domestic environment with CO is generally regarded to be highest in properties with open flue appliances[3], owing to the potential for flues to become blocked if poorly maintained, and appliance fumes subsequently being vented into a room rather than outdoors. Whilst the installation of open flue appliances in domestic properties is now restricted under certain circumstances under the Gas Safety (Installation and Use) Regulations 1998, and most new installations tend to be room sealed appliances typically with balanced flues, the results of this work suggest that there are still many properties in the UK where open flue appliances are currently installed. A 2009 Report compiled by the Department of Communities and Local Government[2], in which deaths in 2007 attributable to carbon monoxide poisoning in homes were quantified, reported 35 deaths in total, 17 of which occurring in flats, houses and bungalows. The % of deaths attributable to central heating boilers, cookers, room heaters, gas fires and back boilers were 21.4, 7.1, 25.0, 10.7 and 7.1 respectively. In the households surveyed as part of this study, 45% were found to have an open flue appliance. The proportion of householders reporting a history of CO problems in their home was 6%, while 6% of householders reported that their alarm had triggered in the past[j]; the proportion of householders reporting a CO problem or that their alarm had triggered previously was 11% in those with an open flue appliance; interestingly the equivalent figure for those with an appliance with a balanced flue was higher, at 15%. These data are consistent with the view that the measures taken by stakeholders, e.g. Gas Safe Register and HSE, to highlight the risks of problems associated with unsafe fuel appliances in the home, appear to be having the desired effect.

The standard BS EN 50292 offers guidance to consumers on how alarms should be deployed in the home to maximise their ability to detect abnormally high levels of CO. Key recommendations are to deploy alarms in rooms with potential sources of CO, and deploy the alarm at a sufficient height (but not too close to the ceiling), so that any CO emanating from appliances and entrained in the rising warm air is detected as quickly as possible. The home surveys carried out by Gas Safe Register Inspectors as part of this study highlighted that 23.6% (25/106) of alarms were incorrectly deployed, the most common reason being that the alarms were inappropriately positioned in the room (e.g. wrong height from floor), the case for 76.0% of those incorrectly deployed; in 24.0% of cases, the alarms were identified as being not sufficiently close to potential sources of CO in the home. Whilst there was no evidence that incorrectly deployed alarms were more likely to fail gas testing, it is possible that their ability to detect abnormally high levels of CO may be impaired. Interestingly, the survey data suggested that alarms were significantly more likely to be incorrectly deployed when deployed in lounges (35.5%), compared to kitchens (9.8%). There was also some evidence suggesting that homeowners were more likely to deploy alarms incorrectly (26.3%), than landlords deploying alarms in rented properties on tenant's behalf (20.0%), although the latter difference was not large. The latter may contribute to the

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[i] *For example, yellow rather than blue flames, staining on or around appliances, pilot lights frequently blowing out and increased condensation on windows (taken from HSE's Gas Safety Guidance).*

[j] *Information on whether the alarm was genuine or false (e.g. attributable to tobacco smoke) was not collected.*

observed tendency for incorrect deployment of alarms in lounges, given that homeowners appeared to prefer deploying their alarms in such a location. Considering HSE's 2006 review of Gas Safety[3] reported that CO poisoning related incidents most commonly involved poisonings in lounges and bedrooms, maximising the potential of alarms to detect CO leaks as early as possible in such rooms in particular is obviously critical.

5 REFERENCES

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3 *Review of domestic gas safety: Report for the Health and Safety Executive.* Frontline Consultants 2006.

4 *BSI Standard BS EN 50291 : 2001 Electrical apparatus for the detection of carbon monoxide in domestic premises*. BSI 2001

5 *BSI Standard BS EN 50292 : 2002 Electrical apparatus for the detection of carbon monoxide in domestic premises. Guide on the selection, installation, use and maintenance*. BSI 2001

6 *Underwriters Laboratories Standard UL 2034 2nd ed. (1996 and revisions). Single and multiple station carbon monoxide alarms*. Underwriters Laboratories Inc 1996

7 *National Fire Protection Association NFPA 720 Standard for the Installation of Carbon Monoxide (CO) Detection and Warning Equipment*. NFPA 2009 Edition

8 *Joint industry project on carbon monoxide issues: Long-term reliability of domestic CO alarms*. Contract Research Report 360/2001. Prepared by Advantica for HSE. HSE Books 2001

9 G Pool and J Cotton. *Continued appraisal of domestic CO alarms*. Research Report 165. Prepared by Advantica for HSE. HSE Books 2003

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11 B.S. Hobbs, A.D.S Tantram, R. Chan-Henry, *Liquid electrolyte fuel cells*, in: Moseley, P.T, Norris, J.O.W and Williams D. E. (Eds.), *Techniques and mechanisms in gas sensing.* The Adam Hilger Series on Sensors, pp.167-174. Taylor & Francis 1991

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6 APPENDIX

6.1 QUESTIONNAIRE

Domestic CO Alarm Installation Questionnaire

Please complete this form each time that a CO alarm is exchanged, during an inspection of domestic premises

1. Description of Location

Address:

Property Type (tick one):

Flat	
Maisonette	
Bungalow	
Terraced	
Semi-Detached	
Detached	
Caravan	
Boat	
Other	

Room Type (tick one):

Bed-sit	
Bedroom	
Landing	
Hallway	
Lounge	
Kitchen	
Cellar	
Outhouse	
Other	

Appliances Installed (please tick all that apply)

Flueless	
Open flued	
Balanced Flue	
Solid Fuel	
Oil	

Tenure (tick one)

Owner occupied	
Rented	

N.B. Where a CO Alarm has been collected from a rented property, permission must be sought from the Landlord to do so.

If possible, sketch plan of installed location of the alarm, giving height above floor level, and including major features, such as fuel-burning appliances, and approximate overall dimensions:

Is the installation generally in accordance with the recommendations of BS EN 50292

Yes/No

Additional comments on the location?

2. Description of CO Alarm

Manufacturer: ______________________

Model Number: ______________

Power Source (circle):

Dry Battery   Other Battery

Does the unit claim approval to BS EN 50291 (Yes/No)?

Approximate Age (unless new): ______ years

Serial Number or Production Date Code: __________

Any additional comments on the appearance e.g. External damage or discolouring?

3. History and Experience

Are the occupants aware of any CO-related problems at these premises

Has the CO alarm triggered **YES/NO**

If so, are the reasons known?

Has the CO alarm been tested on a regular basis **YES/NO**

If yes, how often?

If so, was this by pressing a TEST button **YES/NO**

Why was the CO alarm originally installed?

Was the occupier involved in the selection/supply **YES/NO**

If so, was BS EN 50291 a consideration **YES/NO**

Does anyone smoke in the room that contains the CO detector or is there any visual evidence of smoking in the property (smell or discoloration) **YES/NO**

Has the homeowner/ tenant/ landlord recently decorated in the room containing the CO detector?

Does the homeowner/ tenant have more than one CO detector **YES/NO**

If yes, why & where are they located?

Any other comments or information given by the occupier?

4. Contact Details

Please provide the contact details in case any further information is needed.

Name: ____________________ Tel No: ______________ Date: _____________

YOUR CO-OPERATION IN THIS PROGRAMME IS GREATLY APPRECIATED

Figure A1: Questionnaire filled in by Gas Safe Register Inspectors during CO alarm collection visits

6.2 DETAILS OF TEST PROCEDURES

6.2.1 General

The test parameters were monitored using the calibrated instruments listed in Table A1.

Table A1 – Instruments used to monitor test conditions

Parameter	Unit	Monitoring Instrument
CO concentration	ppm	MultiRAE CO sensor
O_2 concentration	%	MultiRAE O_2 sensor
Temperature	°C	Humidiprobe Temperature & RH Monitor
Relative humidity	%	Humidiprobe Temperature & RH Monitor
Air pressure	kPa	Air Instrument Resources Ltd. Micromanometer MP6KD
Air velocity	m/s	TSI VelociCalc Plus Anemometer
CO alarm activation (for record only)	n/a	Casella Cel-460 Dosimeter (sound level) (alarm sound time also recorded by observer)

The following procedure was performed in order to achieve the required CO concentrations in the test chambers within the required times for the two standards:

- the air in the chamber was raised to the required humidity using mass flow controllers (MFCs) mixing dry air (approx 1% RH) with air humidified by passing through a water bubbler

- the volume of a 1% CO in air mixture (derived from a certified gas cylinder) required to mix with the volume of air in the test chamber to achieve the test concentration (330 or 400 ppm) was injected into the chamber via a syringe over a period of a few seconds

- CO from a certified gas cylinder at the test concentration (330 or 400 ppm) was fed into the chamber via a MFC at the appropriate flow rate to maintain the required concentration

The time taken for the CO in the chamber used in the BS EN tests to reach the lower limit of the specified concentration range of 300 ppm was 45 ± 5 sec (BS EN 50291 does not specify a time but states that the gases must applied "in a step change"). The time taken for the CO in the chamber used in the UL tests to reach to reach the lower limit of the specified concentration range of 390 ppm was 75 ± 15 sec (UL 2034 specifies that the level should be established within 3 min).

6.2.2 BS EN 50291 test procedure

The test conditions specified by BS EN 50291are:

- Before commencing any test sequence, the apparatus shall be allowed to warm-up for a minimum period of 1 hour.

- The tests shall be performed using air and test gases of constant temperature ± 2 ºC within the range 15 ºC to 25 ºC throughout the duration of each test.

- The tests shall be performed using air and test gases of constant relative humidity (r.h.) ± 10 % r.h. within the range 30 % r.h. to 70 % r.h. throughout the duration of each test.

- The tests shall be performed using air and test gases at ambient pressure ± 2 kPa within the range of 86 kPa to 108 kPa throughout the duration of the test.

- Air velocity of 0.3 ± 0.2 m/s

The tests were performed by locating the alarm in a small volume test chamber, in order to minimise the mixing time, and subjecting it to the gases above using a controlled atmosphere generation system, based on blending CO gas from certified gas cylinders with humidified air at a controlled temperature, in accordance with the requirements of BS EN 50291 as detailed above. The CO concentration in the test chamber was continuously monitored. The test chamber is shown in Fig A2.

Figure A2: Equipment set up for the BS EN 50291 test

6.2.3 UL2034 test procedure

The relevant requirements of the standard are:

- The carbon monoxide alarm shall be installed in a chamber, having a volume of at least 1 cubic foot (0.0283 m^3), constructed so as to permit accurate monitoring and control of chamber air temperature and humidity and oxygen and carbon monoxide concentrations. The following conditions shall be established within the test chamber and maintained throughout the test:

    - Ambient temperature at 23 ± 3°C or a higher temperature if specified by the manufacturer.

- Relative humidity at 50 ± 20 percent.
- Oxygen concentration at 20.9 ± 1 percent.
- The alarms shall then be placed in a test chamber, either individually or in a group, and operated for 15 ±5 minutes. The test chamber shall then be sealed. Carbon monoxide shall be introduced into the test chamber and slowly circulated in the chamber to produce a uniform concentration of 400 ±10 ppm. This level of carbon monoxide shall be established within 3 minutes after sealing the chamber and shall be maintained throughout the remainder of the test. Once the specified carbon monoxide level has been established, the alarms shall actuate within the time range of 4 to 15 minutes, but not to exceed 15 minutes.

The tests were performed using the apparatus shown in Fig A3.

Figure A3: Equipment set up for the UL 2034 test

HSE

Health and Safety Executive

Domestic carbon monoxide alarms

Long-term reliability and use scoping study

Carbon monoxide (CO) is an invisible, odourless and tasteless gas produced in the home by any fuel-burning appliance. Properly installed appliances are designed to combust fuel efficiently and produce little waste CO; any CO that is produced is either vented from the room to outside by a flue or chimney, made inert by a catalytic converter associated with the appliance, or is left to disperse naturally.

CO alarms are widely recommended as one of a number of important measures to protect against the health risks associated with CO leaks from fuel burning appliances. The expected lifetime of CO alarms has been increasing since their introduction in the mid-1990s and some current models have an expected lifetime of more than 6 years under normal operation. This report seeks to derive evidence on the reliability and use of CO alarms currently employed in UK domestic settings, to support consumer advice regarding their effectiveness and usage.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the author alone and do not necessarily reflect HSE policy.

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