Communities and Local Government

Study on the Provision of Carbon Monoxide Detectors Under The Building Regulations

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The findings in this report are those of the authors and do not necessarily represent those of the Department for Communities and Local Government.

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Chapter 1

Executive summary

This report makes a recommendation to Communities and Local Government regarding the provision of carbon monoxide (CO) detectors under the building regulations. This study has taken into account many factors influencing this decision including costs, benefits, reliability and effectiveness of detectors.

A detailed analysis has been carried out of deaths, injuries and reportable incidents concerning all fuels over recent years. Annual deaths from CO poisoning total about 250, but about 170 of these are most likely associated with suicide. Thus about 80 are not self-inflicted and about half of these are attributable to CO from a combustion device. This number compares reasonably closely with the CO-Gas Safety database of 27 deaths. It is possible to track CO incidents and injuries in a similar fashion.

1) Considering **natural gas and LPG**, the overwhelming numbers of incidents occur from elderly open-flued appliances, because modern gas appliances already contain a secondary safety system. When looking forward, the level of incidents (base case) is assumed to fall by 66%.

2) Considering **solid fuel** appliances, the majority of these, for valid technical reasons cannot be fitted with an on-board safety device. With regard to the future, no improvement in appliance performance is assumed.

3) **Oil** products have an excellent safety record and inherently are low risk due to secondary safety systems.

4) Most combustion appliances are designed to be installed in conventional buildings; **caravans and boats** have very small air volumes and are very well sealed. Almost any deterioration in performance (even transient) can result in a serious situation.

The average cost, maintenance implications and average lifetime of CO detectors have been established. The benefits of CO detectors have been based upon the Department for Transport (DfT) figures for how much money it is worth spending to prevent a fatality. Four cost benefit analyses have been carried out using a low, base and high risk scenario in each case. This provides a numerical value to establish the best scenarios for installing a CO detector.

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.

It is recommended that a CO detector be installed with the installation of every new combustion appliance except where gas and LPG appliances conform to the European Gas Appliance Directive or where a pressure jet oil appliance is installed.

Chapter 2

Introduction

GASTEC at CRE (GaC) were commissioned by Communities and Local Government to undertake a desk-based study on the provision of carbon monoxide (CO) detectors under the building regulations.

This review has carried out a detailed study into the available technology. Included in this review is a comparison of the current prices of detectors available on the UK market. Also compared were the technical specifications of the detectors, including the standard to which they conform (and hence the levels at which the alarm will operate) and the type of power required to operate the detector.

The next part of this study includes a review of the reliability and location of the alarms. This has included looking at the number of cases where CO detectors have been present but have not alarmed when they should have done.

In order to understand the current situation fully, a detailed analysis of the deaths and injuries caused by CO poisoning has been carried out. This was partly to clarify the numbers which are often quoted, but include factors such as suicide, which are not relevant to this study. Another reason for analysing the casualty statistics was in order that a detailed cost benefit analysis could be carried out.

The cost benefit analysis forms the final part of this report and gives a cost benefit ratio. This forms part of the basis on which GaC make the final recommendations to the Department.

Chapter 3

Review of available technology

A market survey of the available technology has been carried out and all the technical specifications of the various CO detectors compared. The major factors included in this comparison were cost, lifetime, alarm levels and the standard to which the CO detectors had been tested. The market survey included the most commonly available brands on sale in the UK. These were Honeywell, Fire Angel, Kidde, BRK Dicon and Ei.

All the detectors researched here conform to the latest European and British Standard which is BS EN 50291:2001 apart from the detector manufactured by BRK Dicon and this conforms to the latest North American Standard UL 2034. The alarm conditions as stated by BS EN 50291:2001 are shown below in Table 1.

Table 1: Alarm conditions as set out by BS EN 50291:2001 [BS EN 50291:2001]

CO Concentration/ppm	No alarm before	Alarm before
30	120 minutes	–
50	60 minutes	90 minutes
100	10 minutes	40 minutes
300	–	3 minutes

The health effects of CO are shown in Table 2 below in terms of the percentage of carboxyhaemoglobin (COHb) in the blood. CO is a colourless, odourless gas which is rapidly absorbed through the lungs. It reversibly binds with haemoglobin and forms COHb. CO combines with haemoglobin over 200 times more readily than oxygen does and therefore it reduces the oxygen carrying capacity of the blood. CO further reduces the oxygen carrying capacity of the blood by having an effect on the dissociation of oxyhaemoglobin.

Table 2: Health effects of COHb blood levels on healthy adults [BS EN 50291:2001]

% COHb	Effects
0.3–0.7	Normal range in non-smokers due to endogenous CO production
0.7–2.9	No proven physiological changes
2.9–4.5	Cardio-vascular changes in cardiac patients
4–6	Usual values observed in smokers, impairment in psychomotor tests
7–10	Cardio-vascular changes in non-cardiac patients (increased cardiac output and coronary blood flow)
10–20	Slight headache, weakness, potential burden on foetus
20–30	Severe headache, nausea, impairment in limb movements
30–40	Severe headache, irritability, confusion, impairment in visual acuity, nausea, muscular weakness, dizziness
40–50	Convulsions and unconsciousness
60–70	Coma, collapse, death

The lifetime of the CO detector unit is also a major factor which was compared in the market survey. The majority of detectors on the UK market have a lifetime which directly relates to the lifetime of the sensor unit. In most cases this means the unit has to be replaced at the end of the sensor lifetime. In a few cases the sensor can be replaced and so the lifetime of the unit is twice as long. It is recommended by the manufacturer that the unit be replaced after two sensor lifetimes. Of the detectors looked at in this survey, only the Ei detectors were available to buy with replaceable sensors. The effect of being able to buy a new sensor means the unit lifetime is increased from 5 to 10 years. All the remaining detectors which were considered in this study had lifetimes ranging from 5 to 7 years, with the average lifetime being 6 years. It is this average which has been used for the cost benefit analysis in this report. This average has been calculated using the product literature from a range of detectors available on the UK market.

The cost of CO detectors available on the UK market varies in part due to the range of different manufacturers, but also due to the variability in power options. There are four main types of unit available on the market and these are: mains 230 V with battery backup, mains without battery backup, units with replaceable batteries and units with non-replaceable batteries.

There are advantages and disadvantages associated with each way in which the unit is powered. In the case of a mains-only detector, the obvious disadvantage is that in the case of a power cut, the detector will not be able to function, but the advantage is that is not easy to tamper with. Those detectors which have non-replaceable batteries are much more tamper proof, but because they are in a sealed unit it means the lifetime of the detector is restricted to the lifetime of the batteries.

A mains powered detector with battery backup has the major advantage that in the event of a power cut the detector will still alarm if CO is detected. Such a scenario might arise in the event of an electric power cut initiating the use of an old gas fire. This advantage is also realised if the power supply is cut to the house for any other reason such as maintenance. The only disadvantage to this type of detector would occur if the batteries were removed (for future replacement or accidentally) and there was also a power cut, but the chances of this are minimal and the advantages far outweigh this disadvantage.

It must be noted here that there are mains powered detectors available with a cord and plug but this is not considered tamper proof as it could be unplugged. A more tamper proof option is to have the detector hard wired in a similar way to, for example, a standard smoke alarm. This option means that not only does the detector itself cost more to purchase initially but also there would be a fee required to fit the detector by a qualified electrician. At current prices, it is estimated that this installation cost would be in the range £90–150. However, it is anticipated that if CO detectors were to become compulsory under building regulations then the economies of scale could result in some reduction in this installation fee.

From this analysis several major points can be made to help the cost benefit analysis. The first of these points is the price per year of buying and maintaining a CO detector. From the range looked at in this study, the average price of a unit was £31.37. Owing to market sensitivity, this average is not a weighted average, as it was calculated by looking at the prices of the detectors considered in this study. The detectors looked at ranged from as little as £17.13 per unit to £68.88 per unit. Two detectors of these considered contain replaceable sensors (both Ei detectors) – these detectors have all the same functions but one has a digital display and the other does not. These are both mains powered detectors with replaceable sensors. The price of the replaceable sensors is £21.30 and once fitted they give the unit another 5 years of life.

If CO detectors were to be compulsory under building regulations then almost certainly the price of each unit would be reduced due to the economies of scale, however as CO detectors are already produced at the level of tens of thousands per year such reductions may be modest.

Due to the variation in lifetime, cost and power options, one type of detector has been chosen to use as a base case scenario for the cost benefit analysis. The detector to be used as this base case scenario is one with a sealed battery unit which lasts the lifetime of the detector. This means that at the end of the lifetime, the detector should be thrown away and a new one installed. Of the range of detectors looked at for the purposes of this study, there are two which are of this type. The average price of these two units is £23.62 and it is this cost which will be used. As these detectors do not draw any mains power or require replacement batteries or sensors, no maintenance cost will occur. However, it should be noted that a detector running on mains power with battery backup would cost in the region of £1.50 per year to operate including the cost of replacement batteries.

Chapter 4

Review of reliability and location of alarms

There are several recommendations available to the public as to the quantity and location of CO detectors in their dwellings.

In the case of installing a single detector, the recommendations generally state that the detector should be placed higher up in the room but not too close to the combustion appliance. Placing the detector higher up means it is more likely to sense CO quickly as the CO is entrained in the warm air from the combustion appliance.

It is also generally recommended that if a number of CO detectors can be installed then one should be placed in every room in the dwelling which has a combustion appliance fitted in it.

There are some specific cases where advice differs from the generalisations mentioned above. By way of example, in the case of bedsits, the advice is to place the detector nearest the sleeping area to alert occupants when asleep. If the combustion appliance is located in a cellar or boiler room, the detector should be placed just outside the door to this room in order that the alarm would be heard if the detector went off.

If an appliance were to be installed in every room with a combustion appliance then this could become costly for some homes. For the purposes of this study, the cost benefit calculations have been performed assuming there would be one detector installed in every dwelling in the UK, where a new combustion appliance was installed.

It is generally accepted that modern CO detectors with electrochemical sensors are extremely unlikely to give a false alarm. However, with the older type of detectors, false alarms are more frequent and the majority of reported calls for false alarms relate to this type of detector.

Chapter 5

Review of effectiveness of detectors

The effectiveness of CO detectors in detecting faults and preventing casualties can be split into several areas:

- the historical incidence of CO deaths and injuries
- what fractions of those could be avoided with the use of CO detectors fitted retrospectively to every appliance
- what would be the likely number of incidents, if CO detectors were to be installed with new appliances?
- how effective (in practice) CO detectors are likely to remain and how they might encourage less conservative behaviour?

To deal with these in turn:

A detailed analysis of the death and injury statistics has been carried out.

Office for National Statistics data

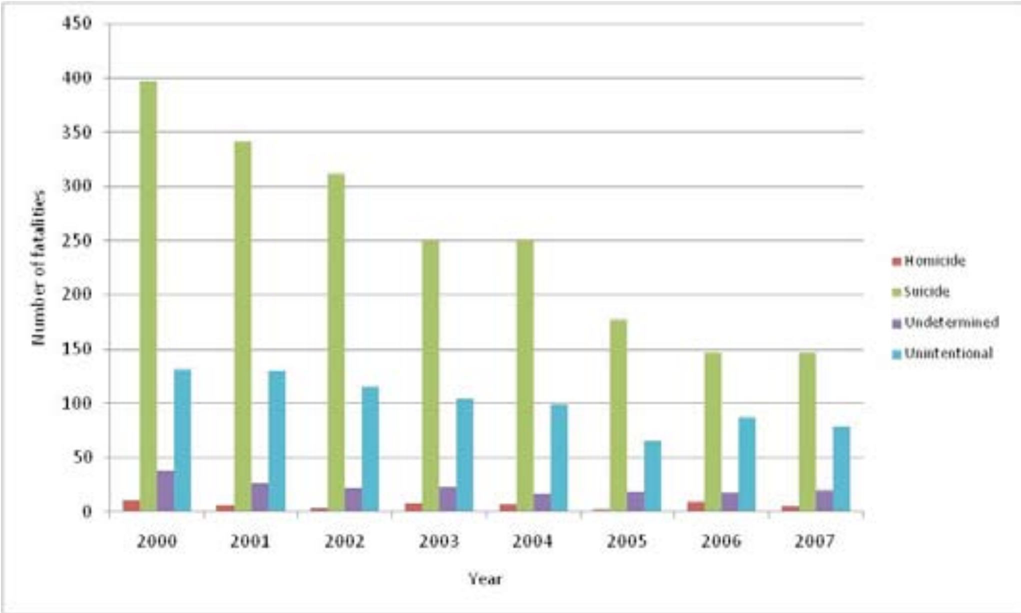
Although a large number of deaths in England and Wales occur due to the toxic effect of CO, more than two-thirds of these deaths in 2007 were of intentional or undetermined intent. The published figure by the Office for National Statistics (ONS) for England and Wales in 2007 was 251 deaths arising from the toxic effect of CO [ONS, 2009]. This figure itself had fallen from nearer 500 in the year 2000.

This figure was then investigated and broken down using the International Statistical Classification of Diseases and Related Health Problems (ICD) codes which are used to classify deaths. In the case of carbon monoxide, ICD code T58 refers to the toxic effect of CO as the cause of death. This can be broken down into the four following categories (see Figure 1):

- homicide
- suicide
- unintentional
- undetermined

Undetermined deaths, although they are often suicides, cannot be deemed intentional.

Figure 1: Fatalities arising from CO between 2000 and 2007 by type of fatality [ONS, 2009]



In 2007, there were 251 deaths due to CO poisoning and 79 of these were unintentional. This was calculated using the individual ICD codes. However, this figure of 79 includes accidental deaths in all locations and arising from all types of appliance in England and Wales.

To further understand the risk created by combustion appliances in the home this figure was separated into various categories, relating to whether the incident was in a residential dwelling, in an industrial location or as a result of a transport accident. This breakdown is shown below in Table 3.

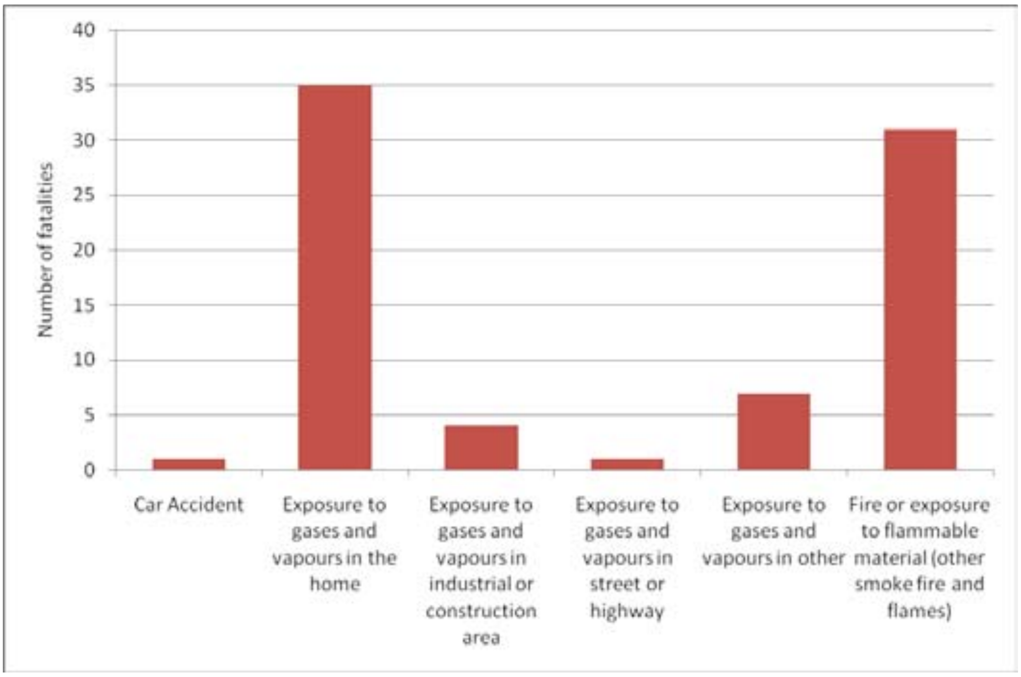
Table 3: Location and number of fatalities from CO in 2007 [Wells, 2009]

Location of incident	Number of fatalities in 2007
Car accident	1
Exposure to gases and vapours in the home	35
Exposure to gases and vapours in industrial or construction area	4
Exposure to gases and vapours in the street or highway	1
Exposure to gases and vapours in other location	7
Fire or exposure to flammable material (other smoke, fire and flames)	31

One of the largest causes is, therefore, CO produced during uncontrolled building fires (accountable for 31 of the 79 deaths in 2007). CO detectors are not designed to save lives in this situation. These persons would have been better warned of risk by a smoke alarm. Therefore, the 35 deaths which are reported to have occurred due to exposure to gases and vapours in the home are those which are relevant to this study as they generally apply to situations involving a combustion appliance. This analysis has been confirmed with the ONS. They do, however, include deaths occurring in garages, although these incidents are known to be in the minority.

This breakdown by location is also represented in Figure 2 below.

Figure 2: Location of deaths arising from CO in 2007 [ONS, 2009]



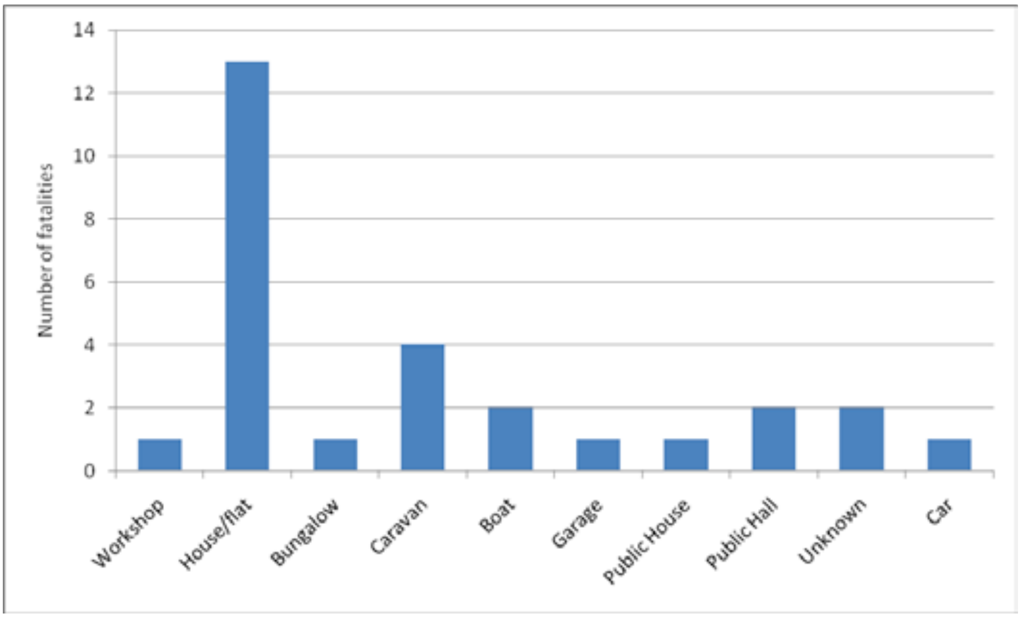
It should be noted here that although the data shown in Figure 2 above differentiate between transport accidents and exposure to gases and vapours in the home, those incidents in the home do include deaths in boats and caravans, where the boat or caravan is being used as a permanent dwelling. The complexities arising from this will be discussed further.

The Carbon Monoxide and Gas Safety Society data

A list of CO-related deaths is also published by The Carbon Monoxide and Gas Safety Society (CO-Gas Safety), and records details about each death to have occurred in the UK due to the toxic effect of CO. The deaths on this list are not compiled from any official statistical source but are compiled from news items and coroners reports. One part of these records refers to the location of the incident. This is shown in Figure 3. As can be seen, 14 of the deaths occur in houses, flats or bungalows. It is these deaths which would be reduced as a result of installing CO detectors in residential dwellings.

Figure 3 rationalises the number of CO deaths and incidents on a historical basis. It may be seen that less than half of deaths occur within domestic dwellings (as covered by building regulations) and that disproportionate numbers are associated with boats and caravans.

Figure 3: Location of deaths in 2007 due to the toxic effect of CO [CO-Gas Safety, 2009]



Below is the CO-Gas data broken down firstly by fuel (see Figure 4) and secondly by appliance type (see Figure 5).

Figure 4: Deaths from CO in 2007 shown by fuel type [CO-Gas Safety, 2009]

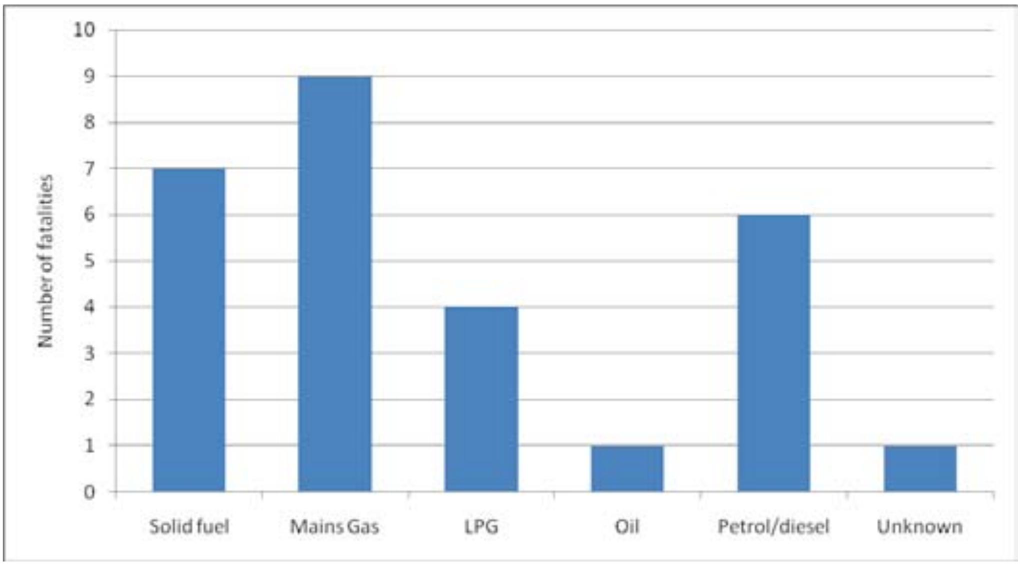
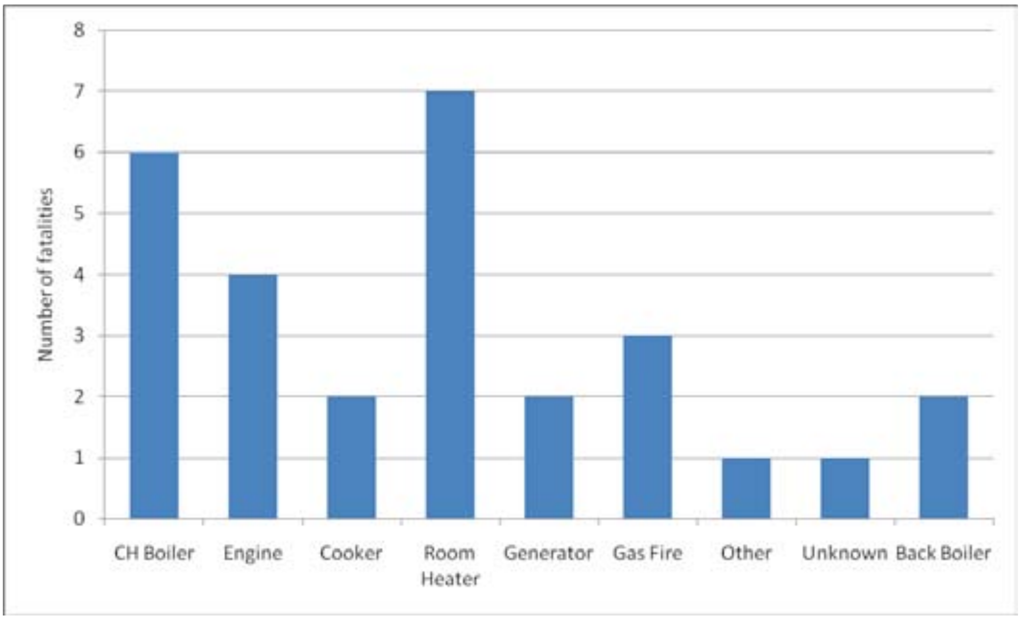


Figure 5: Deaths from CO in 2007 shown by appliance type [CO-Gas Safety, 2009]

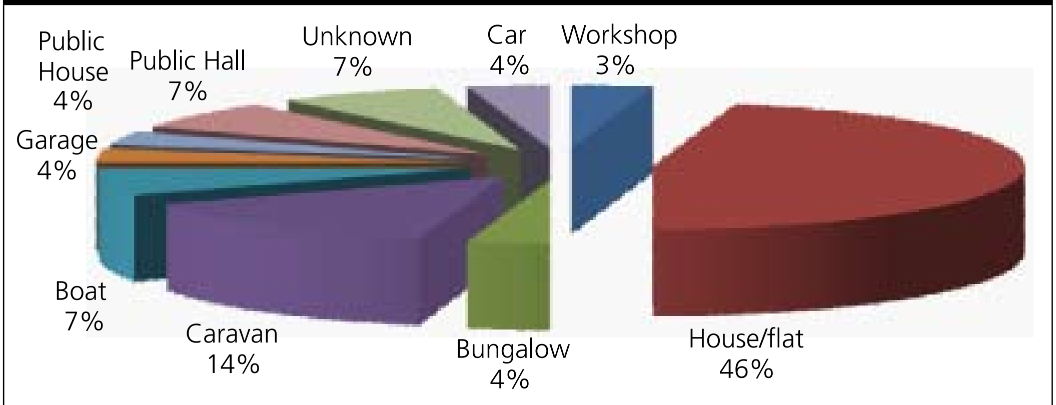


A note about the possible numbers of boats and caravans included in the above data sets

The data from the ONS do not differentiate between residential dwellings as covered by Approved Document J (ADJ) and boats and caravans which are used as permanent dwellings as described earlier in this report. There were 35 deaths recorded by the ONS as a result of exposure to gases and vapours in the home.

This loose definition of 'home' does present difficulties hence the author's proposal to use the CO-Gas Safety data (27 deaths, see Figure 6) as a reference point to the more precise location of deaths. Thus in 2007 the CO-Gas Safety data report that 6 deaths were associated with boats and caravans and 14 deaths were associated with houses, flats and bungalows (see Figure 3). Scaling this up to the 35 deaths reported in the ONS data would indicate 7 deaths occurred in boats and caravans and 17 deaths occurred in houses, flats and bungalows (*ie* residential dwellings as covered by ADJ). It is worth noting that these numbers refer to *all* fuels.

Figure 6: Deaths from CO shown by location [CO-Gas Safety, 2009]



Health and Safety Executive data relating to natural gas and liquefied petroleum gas (LPG)

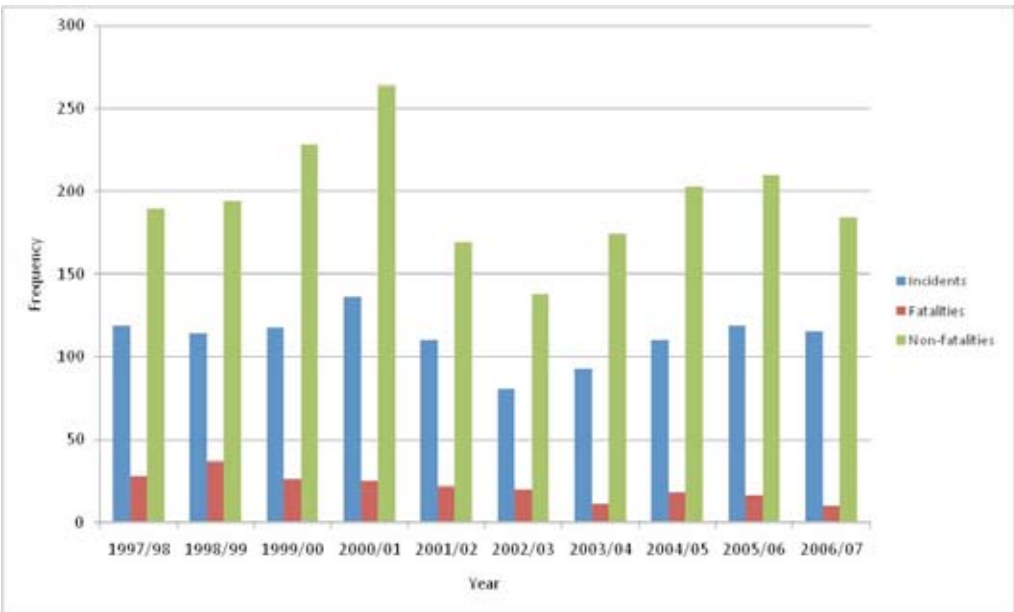
The Health and Safety Executive (HSE) publish separate data on CO incidents involving natural gas and LPG principally arising out of work activities – such as those reportable under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR). RIDDOR covers England, Wales and Scotland. These do not necessarily include *all* CO fatalities within Great Britain. These data are shown in Table 4 along with historic figures from 1997.

Table 4: Historical statistics regarding CO deaths, injuries and incidents due to natural gas and LPG appliances [HSE, 2007]

Year	Number of deaths	Number of injuries	Number of incidents
1997-98	28	189	119
1998-99	37	194	114
1999-00	26	228	118
2000-01	25	264	136
2001-02	22	169	110
2002-03	20	138	81
2003-04	11	174	93
2004-05	18	203	110
2005-06	16	210	119
2006-07	10	184	115

It should be noted that the numbers only relate to deaths where the HSE is involved, for instance, those involving 'work'. These historical statistics are shown in Figure 7.

Figure 7: Fatalities arising from gas and LPG fuelled appliances [HSE, 2009]



Solid Fuel Association data relating to solid fuel (coal, biomass and barbeques)

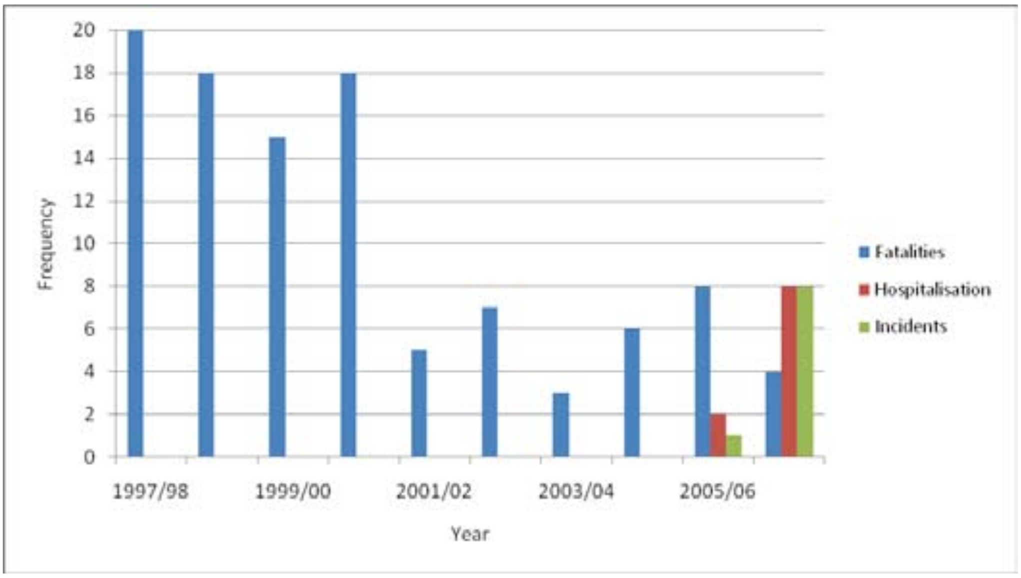
The Solid Fuel Association (SFA) also collects figures regarding deaths and injuries arising from CO from solid fuel appliances in England, Scotland and Wales. These are shown in Table 5.

Table 5: Historical statistics regarding CO deaths, injuries and incidents due to solid fuel appliances [Brooks, 2009]

Year	Number of deaths	Number of injuries	Number of incidents
1997-98	20	N/A	N/A
1998-99	18	N/A	N/A
1999-00	15	N/A	N/A
2000-01	18	N/A	N/A
2001-02	5	N/A	N/A
2002-03	7	N/A	N/A
2003-04	3	N/A	N/A
2004-05	6	N/A	N/A
2005-06	8	2	1
2006-07	4	8	8

Prior to 2005, only fatalities were recorded and so there are no recorded hospitalisation cases before this date. Also the overall number of incidents regarding CO before 2005 was not recorded. These statistics are shown in Figure 8.

Figure 8: Fatalities arising from CO as a result of solid fuel appliances [Brooks, 2009]



The SFA also collect information about the incidents to have occurred each year. These data include (if known) details about the deceased or injured, location of the incident, cause and details regarding the appliance which caused the incident. These data for the year 2006-07 are shown below in Table 6.

Table 6: Fatalities in England, Scotland and Wales in 2006-07 as a result of solid fuel appliances [Brooks, 2009]

Date	Fatalities	Age	Location	Appliance make and model	Fuel	Cause
28/10/06	2		Tunbridge Wells	Unknown	Unknown	Poor maintenance
17/11/06	2	90 and 88	West Yorkshire	Parkray 88G inset	Maxibrite	Blocked fluepipe, chimney in poor state of repair

Also recorded by the SFA are CO incidents which have not resulted in a fatality. These incidents *may* have resulted in an injury but this level of detail is not known from the SFA data. Shown in Table 7 are these incidents. This includes information about the date, age of occupants, location and details on the appliance which caused the incident.

Table 7: Incidents in England, Scotland and Wales in 2006-07 as a result of solid fuel appliances [Brooks, 2009]

Date	Age	Location	Appliance make and model	Fuel	Cause
14/09/06	74 and 77	Derbyshire	Trianco TRG	Anthracite	Blocked flue
02/11/06		Builth Wells	Rayburn	Unknown	Lack of service
02/11/06		Swansea	Wamsler, cooker	Unknown	New installation
21/12/06		Llandrindod Wells	Open fire	Unknown	Fumes
28/12/06		Powys	Unknown	Unknown	Fumes
02/01/07	83	Carmarthen	Rayburn, cooker	Unknown	Blocked flue – swept by Solid Fuel Services in 09/06
06/01/07		Powys	Rayburn, cooker	Unknown	Blocked flue
07/03/07	76 and 46	Harrow	Cooker	Unknown	Unknown

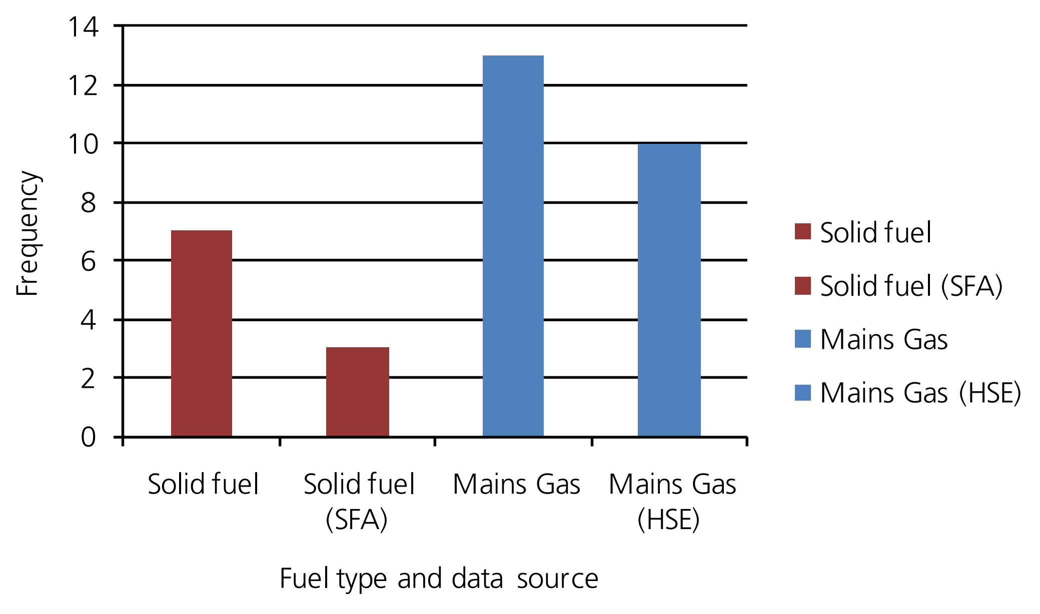
Comparison of above data sets

As should be expected, the above data sets are in broad agreement, especially the totals of the ONS and CO-Gas Safety figures; thus in 2007 these were 28 against 35, but included in the 28 is one car accident. It would thus appear fairly equivocal that the number of UK deaths from CO (other than in building fires) totalled between 27 and 35.

Variations by fuel type are wider, but this is not unexpected as the remit of the HSE is limited and the majority of CO-related deaths now fall outside of its remit. The discrepancies are shown in Figure 9.

A large proportion of the deaths associated with solid fuel are believed to be due to units using anthracite or other smokeless fuels. At least some of the discrepancy between the SFA figures and CO-Gas Safety figures is believed to arise from barbecues or abuse of barbecue products which has historically (from anecdotal evidence) been the case.

Figure 9: Comparison of HSE and SFA figures with CO-Gas Safety figures [Brooks, HSE and CO-Gas Safety, 2009]



A note regarding oil products

Oil products generally have an excellent safety record. Pressure jet burners as used in modern boilers, are extremely unlikely to malfunction in such a fashion as to produce excessive quantities of CO without alerting the householder. The risk from modern vaporising burners is inherently low due to the presence of the fire valve in the air supply.

A comparison of the above data with other CO-related projects

The report will now consider CO incidents and injuries which, according to general media, are believed to be under-reported. This is mainly due to the fact that there is no centralised system for the reporting of incidents such as CO poisoning, coupled with an apparent under-reporting problem attributed to misdiagnosis of patients by doctors and nurses. The symptoms of CO poisoning are often, it is suggested, recorded as the patient having influenza and so many cases may not be correctly reported each year.

Recent data on calls to the Gas Emergency Service (GES) have given a new perspective on these matters. The GES is funded by National Grid and advertises by trade, local and national press and also on television. It is believed to represent about 50% of GB homes overall (this covers England, Scotland and Wales).

Each call received by the GES results in an engineer visiting the house in question. The engineer who attends site will log the visit under one of several complex categories.

The codes used are shown below in Table 8.

Table 8: List of codes used by Gas Emergency Service engineers on site [Aldridge, 2009]

Code used	Explanation
SFU	**Suspected fumes** – means there could be CO present but it could also be smoke or other by-product
BOC	**Active alarm CO evident** – for example, where the CO alarm has triggered but not due to a battery failure and signs of CO are apparent
BOS	**Active alarm suspect CO evident** – is where an engineer believes CO is possibly present, ie the householder has suffered from headaches but not sought medical attention
BFC	**Battery failure CO evident**
BFS	**Battery failure suspect CO evident**

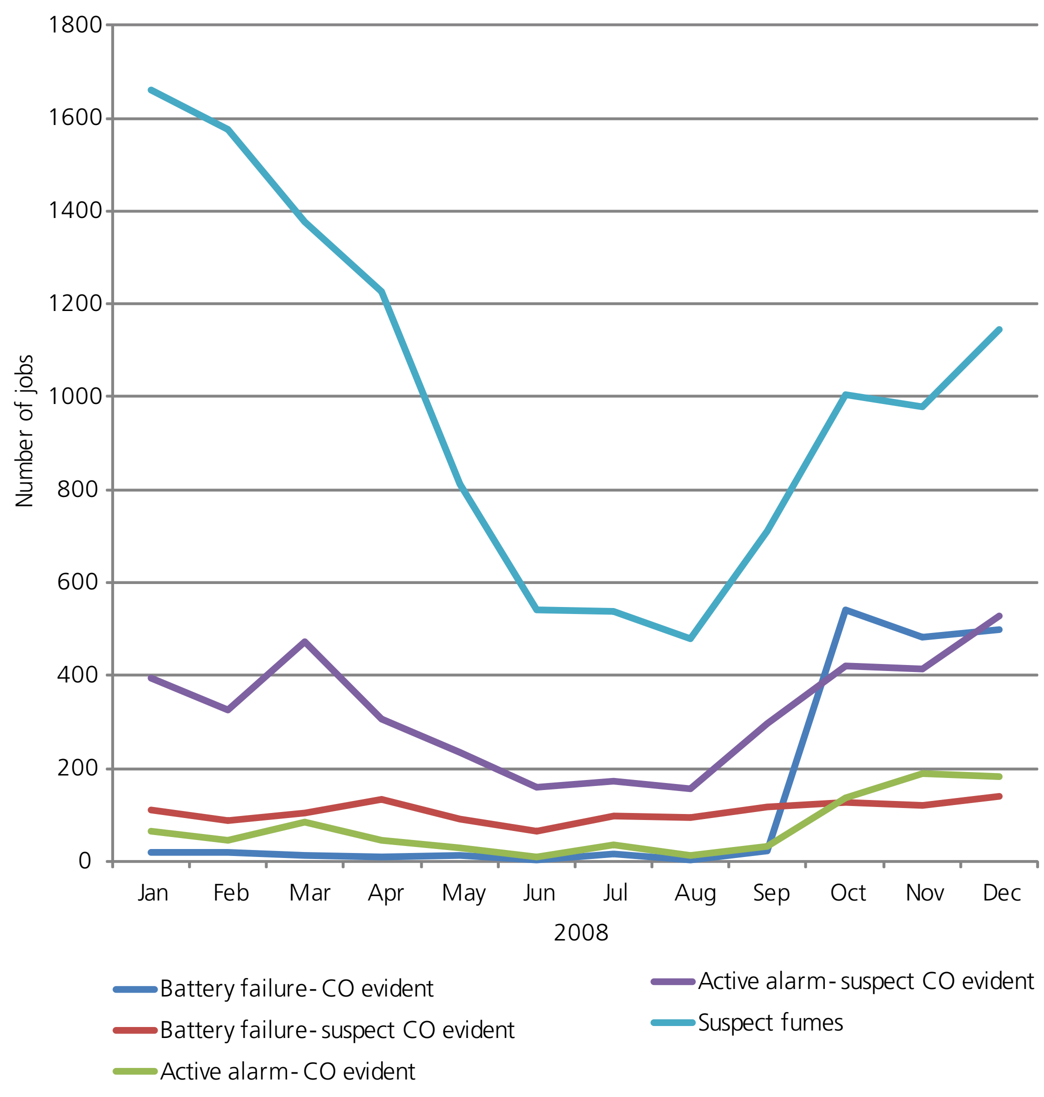
In 2008, about 24,000 calls resulted in 24,000 visits, the vast majority within the target time of 1 hour. In 14,000 of these cases the operative could find no trace of CO or indication that CO might have ever been present (for example, from a faulty appliance), but about 10,000 calls were logged under the five codes listed in Table 8 above. Of these about 6,000 were for suspected fumes and the other 4,000 were directly related to CO.

As explained above, the GES believes it receives about 50% of national emergency calls, thus there are believed to be about twice 4,000 (***ie*** 8,000) CO-related call-outs per annum directly related to CO in domestic dwellings.

It is now necessary to scale up this figure according to the level of CO detectors within GB dwellings. This figure is not well proven, but is believed to lie between 15% [Aldridge, 2009] and 23% [Bielby, 2009]; anecdotal evidence would indicate about 1 in 5 or 20%. Taking this figure would then give a projected total GB CO occurrence of 5 times 8,000 – for instance, 40,000 or 0.2% of GB homes with gas. It could be argued that homes with CO alarms are biased towards low risk houses but there is no evidence to support this or the converse. As very little is known about the location of CO devices within each house and because their cross-sensitivity is sometimes questioned, this can be regarded as an upper limit.

It is interesting to compare the seasonality of 'genuine' CO alarms and battery/detector failures. As can be seen in Figure 10, the former is much more common in winter months. This is due to increased use of heating appliances and fewer open windows. As suspected, the number of calls regarding battery failures is relatively consistent throughout the year.

Figure 10: Number of calls received by the Gas Emergency Service relating to cases of battery failure and active alarms [Aldridge, 2009]



It must be reported that these incident values appear low when compared with (for example) projections that could be made from the Gas Appliance Check Project [Croxford, 2006-07], which would indicate that up to 20% of dwellings offer a severe risk of CO poisoning. It must be said that from the experience of GaC, such a value of 20% seems *very* high for typical UK installations. The data from the Gas Emergency Service and anecdotal evidence from local installers who attend GaC for ACS training all support a much lower figure.

This projected CO occurrence value (0.2%) is important as it indicates that there are unlikely to be extremely large numbers of dwellings containing CO in low but still hazardous concentrations, which might be inferred from some studies of GB gas appliances. This is due to the fact that modern CO detectors integrate CO levels against time (see above). If there really were large numbers of dwellings containing low concentrations of CO then calls to the GES would be expected to be much higher.

Technical perspectives upon the risks of CO poisoning by appliance and fuel type

The effectiveness of CO detectors will now be discussed. To start with, some predictions will be made regarding future incident rates for modern EU Gas Appliance Directive (GAD) compliant gas appliances.

Likely long-term incident rates for modern gas appliances installed by competent operatives

The majority of CO incidents are known to be associated with elderly open-flued appliances installed before 1995. This is supported with evidence from the Gas Appliance Check Project [Croxford, 2006-07] which showed strong correlation between CO levels and age of the appliance, but more importantly, since the introduction of GAD, the overwhelming majority of new gas appliances are either room sealed (that is to say, products of combustion cannot easily enter the living space) or already have an on-board safety system monitoring air quality. Whilst examples of malfunction of this equipment can be identified (nearly always associated with gross installer or manufacturer error) the compulsory use of such second level safety systems has greatly improved appliance safety records across the EU. Such secondary safety systems are, for technical reasons, not available for solid fuel appliances and this will also be discussed further.

The most recent source of data relating to the effect of appliance design upon CO incidents is the HSE Review of Carbon Monoxide Incident Information for 2003-04 [Dhanjal, 2006].

Figure 11: Fatalities by appliance type [Dhanjal, 2006]

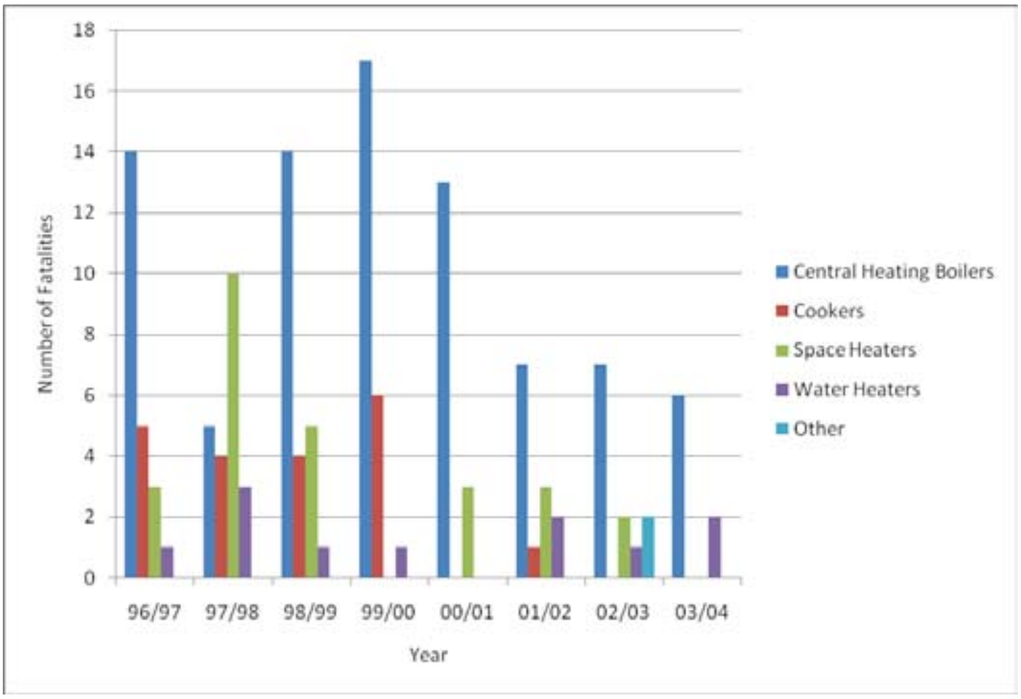
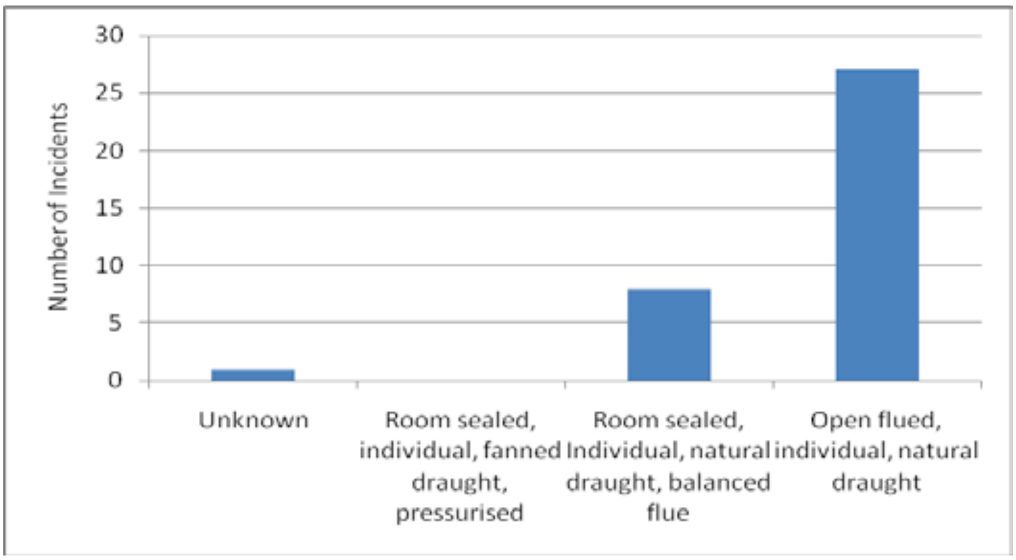


Figure 11 shows the general fall in CO fatalities from the mid 1990s. This is mirrored by incident rates. This is generally believed to arise from the combined effect of improved training brought about by the CORGI's ACS system introduced from 1997 and increasing appliance safety. It can be seen (as expected) that boilers with their high gas input rates remain more of a problem. Figure 12 shows incidents by flue type.

Figure 12: Incidents by flue type [Dhanjal, 2006]



As expected from an engineering perspective, the room sealed individual fanned draught units have the best record. These are precisely the type of condensing boiler unit that now exceed 90% of the UK market for new products and even the remaining 10% are required to have an alternative secondary safety system. The only popular gas products without a full secondary system are gas cookers and each burner is of low gas input (and thereby even if damaged, very unlikely to consume the volumes of gas likely to raise CO levels to a dangerous level within correctly sized rooms). Cookers are presumed to operate intermittently and are required to meet rigorous CO standards.

A simple numerical analysis based upon the above data would indicate that modern gas appliance installations are essentially safe. Therefore it could be argued that the inclusion of secondary safety devices within modern gas appliances negates the need for CO detectors. Where CO detectors might have saved lives in recent years in *new* installations is following gross incompetence by the installer or by the manufacturer. Except in the aviation industry, the author is unaware of the use of tertiary safety devices to address these issues.

It is now appropriate to consider fume re-entry and the correct location for CO detectors. Some of the incidents occurring with modern gas appliances are remote from the appliance, either by failure of the flue gas duct or fume re-entry. Such occurrences are extremely difficult to address with CO detectors; there have, for example, been CO incidences in all-electric houses, the fume having come from the house next door. It is considered outside the remit of this risk assessment to consider the installation of CO detectors in every room in every building in the UK.

This study does however require a numerical value for the relative safety of a new installation over a pre-GAD installation with which the majority of incidents occur; for example in 2004, 2 of the 10 HSE recorded fatalities arose from a DIY installation of a second-hand appliance in a situation illegal since 1984.

As a result of these complexities, this document will assume that new appliances are likely to generate a CO poisoning rate at one-third of that of older appliances. This figure is undoubtedly high and much higher than would be indicated by the Dhanjal (Advantica) data, but it is felt better to err on the side of caution. This figure can then be used to predict the benefits of both CO injuries and deaths per year that are predicted as the possible long-term death rate arising from modern appliances installed by competent installers.

Due to the fact that 2 of the 10 recorded fatalities from gas and LPG arose from gross installer error, there were only 8 deaths in 2006-07 which were directly attributable to the appliance. The introduction of GAD-approved appliances might therefore be expected to reduce deaths to 4 (as this is one-third of the 10 deaths to have occurred in 2007 as a result of incidents involving gas and LPG appliances) and CO-related call-outs (as extrapolated from GES data) to 13,000 per annum. It is considered worthy of restatement that this increased safety factor of three is extremely low by the standards of all current information. The value is loosely based upon the historic ratio of incidents arising from room sealed and open-flued appliances, but elderly balanced flue devices still do not have the level of safety integral to a modern GAD approved appliance. For example, simple extrapolation of the Advantica data would indicate a ratio in excess of 25 for the safety of new to old appliances; but the authors have adopted a very cautious approach.

This reduced value of 4 deaths per year is not to be confused with the effectiveness factor, which is the effectiveness of a CO detector at reducing this rate of gas-related fatalities. This is taken to be 75% for this cost benefit analysis. The figure is not 100% due to incidents arising distant from the appliance of any detector (as described previously). However, this effectiveness factor does assume installation of the appliance in a conventional dwelling; the same arguments do not necessarily hold for caravans or boats where the nature of the construction and the very small air volumes probably do render CO detectors more appropriate.

Likely long-term incident rates for modern solid fuel (coal and biomass) appliances installed by competent operatives

Future incident rates for modern Combustion Products Directive (CPD) compliant solid fuelled appliances will now be predicted.

Figure 8 shows CO incidents over recent years for solid fuel appliances. The situation is more complex than for gas as, for valid technical reasons, full secondary safety systems are impossible, although modern appliances generally show significant improvements over their predecessors.

This complexity occurs with solid fuel appliances where the vast majority of incidents arise from fume from the appliance itself, although such detectors do not address the problems arising from the misuse of barbeques which although not a cause of death in 2007 have historically been an issue.

The fume re-entry problem discussed with respect of natural gas and LPG does not occur with solid fuel because building regulations require all solid fuel appliances to discharge above and well away from any possible points of re-entry. This is due to pollutants in the fumes from many historical solid fuel appliances.

Due to the inherent nature of solid fuel combustion, *ie* the large fire bed and the cyclic nature of batch-fed operation, the CE marking of solid fuel appliances (under the CPD) is not considered to have been able to markedly improve the CO-related safety of new solid fuel appliances (although CO is one of the measured outputs and degrees of classification for tested appliances). This is in contrast to the GAD, which introduced a step change in the safety performance of gas appliances, especially pertaining to CO, hence the assumption of the new poisoning rate of one-third (*ie* a 66% reduction in incidents) for gas appliances; it may well be much better than this.

The following points consider the issues surrounding this statement.

It must be noted that not all the different data sets investigated as part of this report cover the same geographical area. Therefore it is not a comparison of like-for-like data sets.

The SFA data do not capture the age of the appliance and so it is not possible to draw conclusions supported by quantitative data (as it is for gas). The more fulsome collection of these data is considered important and, unlike gas [Dhanjal, 2006], a detailed investigation of the cause of solid fuel incidents by appliance type has not been published, but the following is based upon strong qualitative/anecdotal evidence:

1) Most solid fuel incidents resulting in death or serious injury occur with anthracite, charcoal or smokeless fuel. This is because, whilst these fuels are inherently high producers of CO they are, more importantly, not associated with the smoke and strong smell of most wood or house coals. These latter signs effectively always act as a warning to householders under extreme conditions (either by smell or visually). The visual evidence would include, by way of example, strong signs of smoke damage to decorations above the leaking appliance. Nevertheless, even wood burning appliances usually emit significant quantities of CO. Good quality wood-based charcoal as used in barbeques is a particularly dangerous fuel in anything other than an outdoor environment.

2) The average level of CO within the flue gas of a solid fuel appliance can be up to 10,000 ppm compared with 100 ppm in gas appliances (only one-hundredth). This means even a small leak from the flue of a solid fuel appliance may produce unacceptable levels of CO within the home, even if below that level required to cause death or a serious injury. Such fume could arise from any solid fuel.

3) Whilst deaths or serious injuries from open fires are almost unknown, the anecdotal evidence of staining above many hearth lintels would indicate spillage often occurs from many open fires under particular fire state and wind conditions. Thus many open fires may be producing low or very levels of CO within the dwelling, which are acceptable to the householder but which may exist for extended periods. This problem may become worse as more houses adopt higher standards of insulation and hence draught-proofing. There were certainly a large number of problems with inglenook fireplaces and double glazing between the years 2000 and 2005 [GASTEC at CRE, 2006]. Anecdotally, this could be producing significant levels of ambient CO levels in some dwellings.

4) Modern appliances of high efficiency (as required by the CPD) inherently have lower flue gas temperatures than those of 30 years ago. This has reduced the risk of chimney fires, but is unlikely to have reduced flue gas deposits (as more tars will condense within the flue) and more importantly it will have reduced chimney draught. This will tend to increase the risk of spillage from defective joints. High efficiency appliances can require more regular servicing.

5) Modern automatically fed biomass pellet and wood-chip appliances should have greater levels of CO safety than batch-fed appliances, but long-term evidence of this is awaited. All of the components within a solid fuel appliance experience more arduous conditions than those within an equivalent product burning natural gas. It may be towards the end of their lives that some of these appliances develop faults with seals or heat exchanger welds that permit fume to enter the living space.

6) It is Government policy to increase the use of solid biomass in domestic dwellings. In light of this, it would seem appropriate to require the installation of a CO detector with every solid fuel installation.

Although the appliances may be slightly improved, the historical family knowledge of the safe use of solid fuel is however decreasing at the same time as the Government is promoting more widespread biomass (wood fuel) use. As a result of these counter issues, this report will assume that future levels of CO incident will remain at current levels. This therefore gives the benefit of 7 deaths per year that is the predicted as the possible long-term death rate arising from modern solid fuel appliances installed by competent installers.

Although historically few CO deaths have been associated with wood (biomass), as indicated above the Government is very keen on increasing sale of such appliances and even the best can produce intermittent levels of CO (within the flue), many hundreds of times higher than from a modern gas appliance. Many biomass appliances can also be operated on coal (even if in contravention of the manufacturer's instructions). Due to these reasons it is recommended that if CO detectors are to be required with solid fuel they should be required with all new solid fuel installations irrespective of the exact fuel.

The long-term reliability of CO detectors

The other factor to consider when reviewing the effectiveness of CO detectors is how they are maintained when they are installed. There are several ways in which the operational effectiveness of the detectors could be lessened due to occupants neglecting the maintenance required.

In the case of battery-powered detectors, this could include not replacing batteries when new ones are required or simply taking the batteries out and not replacing them at all.

By installing CO detectors, either on a mandatory basis under the building regulations or as a result of strong recommendation by installers, there would be no positive effects on maintenance. However in some cases, the installation of a CO detector in some dwellings may result in the occupants having their appliances serviced less regularly. It is considered impossible to allocate a robust evidence-based value to this tendency.

Chapter 6

Cost benefit analysis

6.1 Introduction

In order to best calculate the real benefits of CO detectors, all of the appropriate factors will be converted into monetary terms. This will be carried out in accordance with the government guidelines on the value of a life saved. With regards to injuries caused by CO poisoning, the extent and quantity of the injuries will be assessed and a monetary value assigned.

This section tries to take into account all of the costs and associated benefits arising from the installation of CO detectors in domestic properties. These are shown i. Table 9 below.

Table 9: Factors considered in the cost benefit analysis

Costs	**Benefits**
Initial installation Maintenance and operation	Lives saved Injuries prevented

The average retail cost of CO detectors will be obtained from the price of a range of detectors available on the UK market which meet the current British and European safety standards. This will also take into account the variable maintenance and operational costs, which are dependent on the power supply to the unit and the lifetime of the unit.

Having undertaken a detailed study of the fatality statistics relating to CO poisoning, it has been decided to carry out four separate cost benefit analyses. These will be for:

- natural gas and LPG
- solid fuel
- caravans
- boats

6.2 Outline cost benefit calculation

For the purposes of this study all cost will be calculated in common units, which will be cost per dwelling per year.

Let

$£I$ = Initial installation cost (one-off, per dwelling)

$£M$ = Maintenance and operation (annual, per dwelling)

K = Capital Recovery Factor

$£C$ = Cost (annual, per dwelling)

and

R = Risk (annual, per dwelling)

E = Effectiveness of CO detectors at reducing risk

$£V$ = Value of protection (for example, each life saved)

$£B$ = Benefit (annual, per dwelling)

where the following subscripts refer to different components of the overall benefit

d = deaths

i = injuries

tot = total

The overall annual cost per dwelling is

$$£C = K.£I + £M \qquad (6.1)$$

The annual values of reducing deaths and injuries per dwelling are

$$£B_d = £V_d.R_d.E_d \qquad (6.2)$$

$$£B_i = £V_i.R_i.E_i \qquad (6.3)$$

The total annual benefit is

$$£B_{tot} = £B_d + £B_i \qquad (6.4)$$

The following inequality must be satisfied in order for CO detectors to be cost effective

$$\left(\frac{£B_{tot}}{£C}\right) \geq 1 \qquad (6.5)$$

6.3 Residential classification

For the purposes of this study, the effectiveness of CO detectors will be independent of dwelling type. However, when investigating the number of deaths arising from CO poisoning, the number of deaths which have occurred as a result of industrial accidents needs to be calculated separately. For the purposes of this study, only fatalities occurring in residential dwellings will be taken into account, as these are the fatalities which would be prevented if CO detectors were to be installed under the building regulations.

6.4 Effectiveness of CO detectors

In order to evaluate the effectiveness of CO detectors, each type of fuel appliance will be considered separately. The fuel types to be considered here for residential dwellings are:

1. Gas and LPG
2. Solid fuel

Although not relevant to this study, boats and caravans will also be included here for completeness.

As detailed above, as all *new* gas appliances now have a secondary safety system installed already, such as an Oxy-pilot, the risk of poisoning from CO has already been reduced. Therefore installing a CO detector with every appliance is considered to potentially save 4 lives per year.

The effectiveness of a CO detector at reducing this rate of gas-related fatalities is taken to be 75% for this cost benefit analysis.

In the case of solid fuel appliances the effectiveness rate of CO detectors at preventing deaths and injuries will be taken to be at the full 7 fatalities per year. This rate is due to the fact that, for technical reasons, a solid fuel appliance cannot be fitted with a built-in secondary safety system. Therefore a CO detector would be acting as this secondary layer of safety. This value of 7 deaths per year is reduced by an effectiveness factor which details how many of these deaths might be expected to be saved by the presence of a CO detector. This is taken as 75%. The figure is not 100% due to incidents arising distant from the appliance of any new detector.

In the case of boats and caravans the effectiveness rate of a CO detector at reducing deaths and injuries is taken to be 100%. This is due to boats and caravans being confined spaces and consequently the risk of CO poisoning being so much higher than in any other circumstance.

- **Effectiveness rate for gas and LPG appliances** **75%**
- **Effectiveness rate for solid fuel appliances** **75%**
- **Effectiveness rate for boats** **100%**
- **Effectiveness rate for caravans** **100%**

6.5 The components of the cost benefit calculation

6.5.1 Initial installation

The cost of installing a CO detector in a residential dwelling will be based upon the current prices of a range of CO detectors available in the UK. As a result of the market survey carried out at the start of this report, the average price of a CO detector is £31.37.

As previously discussed in Section 3 a base case detector has been chosen for use in this cost benefit analysis. This is a sealed battery unit which conforms to BS EN 50291:2001. Two detectors of this type were looked at as part of the market survey carried out for this report. There may be other detectors with the same specifications on the market but these two were the only ones found for the purposes of this study. The average price of these two detectors is £23.62 and it is this value which will be used for the purposes of this cost benefit calculation. No separate figure has been allowed for an installation cost. It is assumed this be carried out for free.

In practice this is unlikely to be case if the detector to be installed is anything other than a stand-alone battery-only powered unit.

- **Purchase/installation cost of a CO detector** **£23.62**

6.5.2 Maintenance and operation

Although no servicing of detectors is required, regular testing and/or replacement of the batteries is required. The power to these detectors varies depending on the make and model of the detector. There are four different options for powering a CO detector available on the UK market. These are: mains 230 V AC without backup, mains 230 V AC with battery backup and battery alone (with replaceable and non-replaceable batteries).

Those detectors with battery backup or those powered by replaceable battery alone will require a battery change during their lifetime. This would be required by the householder.

However, the lifetime of these detectors as stated by the manufacturers is often shorter than a long-life battery's lifetime. In some cases the sensor can be tested and changed throughout the lifetime of the detector so these have a prolonged life of about 10 years. The average lifetime of a CO detector (from those reviewed in this market survey) on the UK market is 6 years.

Having included the cost of electricity and the cost of batteries, an annual maintenance cost has been calculated as £1.50 per year.

However, as previously discussed, the base case detector will be a sealed battery unit and so will not incur any maintenance costs.

- **Maintenance cost of CO detector £0.00 per year**

6.5.3 Capital Recovery Factor

When calculating the costs of installing CO monitors it is also necessary to take into account the yearly cost variations as a function of current interest rates and the length of the loan. The Capital Recovery Factor is defined as

$$K = i\frac{(1+i)^y}{(1+i)^y - 1} \qquad (6.6)$$

where i is the rate of interest expressed as a decimal fraction and y is the length of the payback period in years, *eg* in this case y is the lifetime of the detector unit.

Using the Capital Recovery Factor the annual repayment can be calculated as follows

$$A = C.K \qquad (6.7)$$

where C is the amount of capital to be repaid, K is the Capital Recovery Factor and A is the annual payment.

Taking into consideration the current economic climate and the unusually low Bank of England Base Rate, several values for i will be calculated based on the current value and some higher values.

Substituting several values for i and y, a range of values fo. can be estimated:

- $i = 0.03; y = 6 \Rightarrow K = 0.18$
- $i = 0.05; y = 6 \Rightarrow K = 0.20$
- $i = 0.010; y = 6 \Rightarrow K = 0.23$

Three scenarios with these different Capital Recovery Factors have been used to calculate the cost benefit ratios, which are:

- **Capital Recovery Factor 0.18**
- **Capital Recovery Factor 0.20**
- **Capital Recovery Factor 0.23**

It should be noted here that the concept of a Capital Recovery Factor is used conventionally for cost benefit analyses although in this particular case the capital cost of buying the detector is low. Therefore it could be argued that the Capital Recovery Factor is not required for this cost benefit analysis.

6.5.4 Risk of deaths and injuries in the absence of carbon monoxide detectors

In order to analyse the risk of CO detectors if they are not fitted to dwellings, an assessment has been made as to the number of deaths which currently occur per year, per dwelling.

To establish the effectiveness of CO detectors, the statistics relating to the number of incidents of CO poisoning has been investigated. These not only include the annual number of deaths due to CO poisoning but also the number of injuries attributed to CO. Using these figures, a reduction in the number of deaths and the number of injuries will be calculated.

Three cases will be considered for each cost benefit analysis; a high, base and low risk case for each Capital Recovery Factor considered.

To consider the number of deaths and injuries which would be saved by installing a carbon monoxide detector, the historical ratios of injuries to deaths must be considered. For the case of gas and LPG, the HSE RIDDOR figures can be used to calculate this ratio. Since 2000-01 the average ratio of injuries to deaths is 15:1, *ie* for every death which occurred there were also 15 injuries reported in relation to CO poisoning. In the years since 2000-01, the ratio was the highest in 2006-07 when it was 18.4.

Due to the conception amongst the charitable sector that injuries are often misdiagnosed or not reported at all, the author feels it is better to utilise a cautious approach when considering the value of the ratio used in the cost benefit analysis. It is for this reason that the ratio has been taken at 20:1, *ie* for every death, there are also 20 injuries. This calculation is based on the HSE RIDDOR figures which apply to gas and LPG.

To next consider the ratio of injuries to deaths which is used for solid fuel appliances (whilst bearing in mind solid fuel appliances do not have a built-in secondary safety system unlike any gas appliances manufactured after 1955 when the GAD was introduced) it must be noted that due to the quality of the data available relating to the deaths and injuries relating to solid fuel, the author has chosen to adopt the same ratio as for gas and LPG as explained above. This may be a cautious approach but due to the known under-reporting of injuries *and* the fact that solid fuel appliances inherently do not have a secondary safety system. The ratio of 20:1 for a ratio of injuries to deaths has therefore been used throughout the cost benefit calculation.

Using a ratio of 20 injuries to each death (see explanation of HSE RIDDOR figures above) the number of injuries has been estimated. It has been estimated that 20% of these injuries which occur are serious and the other 80% of these injuries are minor. This is an estimate based on general evidence which suggests that few people survive serious poisoning incidents and that the majority of incidents result in a minor injury or no injury at all.

Within the number of injuries caused, these injuries can be classified as serious or minor. This classification affects the value of a statistical injury saved. This means it is not a specific injury which is being considered but a statistical injury that is being valued. However, due to a number of problems within the health and medical professions, these injuries are believed to suffer from an under-reporting problem. The Gas Appliance Check Project [Croxford, 2006-07] would be an example of a document supporting this proposition.

This issue has been addressed by reference to the number of jobs carried out by the Gas Emergency Service. There are currently believed to be about 3,300,000 CO alarms installed in the UK (assuming 15% coverage) and jobs directly related to CO are currently running at about 8,000 per annum. This would indicate a maximum occurrence of 54,000 when corrected for UK coverage.

6.5.5 The value of each death prevented

For the purposes of this cost benefit analysis, the method used to value a life will be willingness-to-pay. This process has been adopted by the Department for Transport (DfT) as the basis for how much money it is worth spending to prevent a road crash fatality. The reasons such a method is adopted rather than a legal compensation figure are:

- it is not a specific individual's life, but a 'statistical life' that is being valued
- the same methodology is used across government and the value placed on a prevented fatality is the result of extensive research

- the willingness of an individual to pay for small changes in their risk of loss of life can be used to infer the value of reducing the risk of death. The DfT uses this method of calculating willingness-to-pay and adds this to the value of lost output, ambulance and medical costs to arrive at the value of a prevented fatality.

Previous estimates of the value of a life saved were £1.64m [DfT, 2007] and in order to update this figure to 2008 figures, the growth in GDP per capita has been used along with the following equation (6.8):

$$1 + \frac{\%\ \text{increase in GDP per capita}}{100} = 1.046 \qquad (6.8)$$

In order to update this to a figure valid in 2008, the UK Gross Domestic Product (GDP) at current market value must be used (this is a quarterly, non-seasonally adjusted value). The estimated, mid-year UK population as estimated by the ONS has been used with this figure of GDP to calculate a nominal GDP per capita growth rate as a percentage for the period July 2007 to June 2008.

The value of a life has therefore been calculated to be £1,723,657 in 2008 values.

- **Value of a life: £1,723,657**

6.5.6 The value of each injury prevented

To be included in this cost benefit analysis, a consideration of injuries and their severity will be considered. For the purposes of this study, major and minor injuries will be classified separately and a different monetary value assigned accordingly.

Due to the perceived under-reporting problem regarding CO poisoning and the fact that there is no central location for the statistics, it is not easy to analyse the injuries caused each year by CO poisoning in the UK.

The number of incidents arising from gas or LPG fuelled appliances is recorded by the HSE and these figures give an indication of the number of injuries sustained.

Again the DfT values have been used for a serious and minor injury, which have then been calculated at 2008 prices using the rise in GDP as for the value of a life.

- **Value of a serious injury: £193,677**
- **Value of a minor injury: £14,932**

6.5.7 Additional factors (not considered in the analysis)

The reduction of injuries caused by CO poisoning would result in a saving by the health service. However, this saving will be negligible in comparison with other benefits.

The installation of large numbers of CO monitors would result in increased electricity demand for the dwelling (either from the grid or batteries), the costs of this will be included in the analysis, however the environmental costs of extra CO_2 emissions (from grid electricity production) or extra resource use (from battery production) will be excluded from the cost benefit analysis.

If the power consumed by one CO detector unit is typically 1 W then the unit will use 8.76 kWh of energy per year. This equates to 3.68 kg/year of CO_2 using a SAP CO_2 emission factor of 0.59 [BRE, 2009]. For the purpose of this calculation, the number of households with mains gas in 2005 will be used and this is 2.2m [Assessment of the size and composition of the UK gas appliance population, GASTEC at CRE, 2005]. Therefore, the installation of CO detectors into every dwelling with mains gas would produce 113,000 tonnes of CO_2 each year. This could equate to a cost in excess of £20m (assuming a future traded value of carbon of ~£60 per tonne).

6.6 Results of cost benefit calculation

Three scenarios have been considered for each type of appliance. These scenarios equate to different levels of interest rate and so affect the cost of installing a CO detector. These scenarios are laid out in Table 10 below:

Table 10: Scenarios for cost benefit ratio

Scenario	Interest rate %
1	3
2	5
3	10

Four different situations have been considered in terms of locations and types of appliances. These are:

- gas and LPG appliances
- solid fuel appliances
- boats
- caravans

The results of this cost benefit ratio analysis follow.

It should be noted here that this cost benefit analysis calculates the cost of installing and maintaining a CO detector in every dwelling with a new combustion device. It is assumed that the householder would replace the CO detector at the end of the detector lifetime.

However, it is known that this would not be the case and some detectors would remain in the dwelling without being replaced. This would considerably raise the risk of death and injury as the occupants would no longer be notified if CO was to become present.

Therefore, the cost benefit analysis is only valid for providing and maintaining CO detectors and *not* in those dwellings where the CO detector is never replaced.

Cost benefit calculation for gas and LPG appliances

The total number of dwellings in Great Britain with gas and LPG has been taken to be 22m [GASTEC at CRE, Assessment of the size and composition of the UK gas appliance population, 2005].

Table 11: Cost benefit analysis for gas and LPG

Gas and LPG	High	Base	Low
Benefit			
Risk of death, R_d	10	4	1
Risk of injury serious, R_i	40	16	4
Risk of injury minor, R_i	1000	64	16
Effectiveness at reducing death, E_d	0.75	0.75	0.75
Effectiveness at reducing injury, E_i	0.75	0.75	0.75
Value of death, £V_d	1,610,000	1,610,000	1,610,000
Value of injury serious, £V_i	172,000	172,000	172,000
Value of injury minor, £V_i	13,000	13,000	13,000
Benefit in terms of deaths, £B_d	12,075,000	4,830,000	1,207,500
Benefit in terms of injuries, £B_i	14,910,000	2,688,000	672,000
Benefit, £B_{tot}	26,985,000	7,518,000	1,879,500
Cost	Scenario 1	Scenario 2	Scenario 3
Initial installation, £I	23.62	23.62	23.62
Maintenance and operation, £M	0.00	0.00	0.00
Interest rate, i	0.03	0.05	0.10
Years of operation, y	6.00	6.00	6.00
CRF, K	0.18	0.20	0.23
Cost, £C	4.36	4.65	5.42
Total cost of detectors in the UK, £	95,924,245	102,378,157	119,313,179
Cost benefit ratio scenario 1	0.28	0.08	0.02
Cost benefit ratio scenario 2	0.26	0.07	0.02
Cost benefit ratio scenario 3	0.23	0.06	0.02

The base level of deaths and injuries here has been assumed at the 2007 rates but reduced to one-third to account for *new* gas appliances (as previously explained in Section 5). The injury rates are, as previously stated, at a ratio of 20 to each death, except in the high case. In this case the minor injuries have been increased to a relatively arbitrary 1,000. This is considered justifiable as it is one-thirteenth of the projected number of GB CO occurrences (Gas Emergency Service data analysed above); which must be considerably higher than those in which health is genuinely affected. This is perceived to be generous as it is expected that less than one-third of these calls result in a minor injury which would be reported. Some of the incidents used to project these values undoubtedly relate to deaths and injuries occurring in buildings outside the remit of ADJ, but in the absence of more definitive data and the wide spread chosen of high to low case this factor has been neglected. As a generalisation the approach now adopted is likely to strengthen the case for compulsory detectors.

Cost benefit calculation for solid fuel appliances

The total number of households with solid fuel has been taken to be 1m.

Table 12: Cost benefit analysis for solid fuel

Solid fuel	High	Base	Low
Benefit			
Risk of death, R_d	10	7	2
Risk of injury serious, R_i	40	28	8
Risk of injury minor, R_i	160	112	32
Effectiveness at reducing death, E_d	0.75	0.75	0.75
Effectiveness at reducing injury, E_i	0.75	0.75	0.75
Value of death, £V_d	1,610,000	1,610,000	1,610,000
Value of injury serious, £V_i	172,000	172,000	172,000
Value of injury minor, £V_i	13,000	13,000	13,000
Benefit in terms of deaths, £B_d	12,075,000	8,452,500	2,415,000
Benefit in terms of injuries, £B_i	6,720,000	4,704,000	1,344,000
Benefit, £B_{tot}	18,795,000	13,156,500	3,759,000
Cost	Scenario 1	Scenario 2	Scenario 3
Initial installation, £I	23.62	23.62	23.62
Maintenance and operation, £M	0.00	0.00	0.00
Interest rate, i	0.03	0.05	0.10
Years of operation, y	6.00	6.00	6.00
CRF, K	0.18	0.20	0.23
Cost, £C	4.36	4.65	5.42
Total cost of detectors in UK, £	4,360,193	4,653,553	5,423,326

The total number of homes with solid fuel according to the English House Condition Survey (EHCS) in 2006 was nearly 330,000 [EHCS, 2009]. However, there is a known disparity between the annual sales of solid fuel appliances and this number of 300,000. These annual sales total around 70,000 to 100,000 each year [Solid Fuel Trade, 2009]. Therefore the author has opted for a cautious approach when calculating the cost benefit analysis and has used a figure of 1m homes with solid fuel appliances. Part of this disparity may lie in the fact that there are known to be large numbers of solid fuel appliances which are extremely irregularly used. It can be argued that a very irregularly used (and thus probably ill-maintained) stove is just as dangerous as a regularly used and maintained appliance. Reducing the number of appliances would have the effect of rendering CO detectors even more effective.

It is not known where the deaths from CO poisoning occur but this cautious approach will allow for this unknown factor.

Cost benefit calculation for boats

There are estimated to be 100,000 boats in the UK [Watts, 2009].

Table 13: Cost benefit calculation for boats

Boats	High	Base	Low
Benefit			
Risk of death, R_d	6	4	2
Risk of injury serious, R_i	24	16	8
Risk of injury minor, R_i	96	64	32
Effectiveness at reducing death, E_d	1.00	1.00	1.00
Effectiveness at reducing injury, E_i	1.00	1.00	1.00
Value of death, £V_d	1,610,000	1,610,000	1,610,000
Value of injury serious, £V_i	172,000	172,000	172,000
Value of injury minor, £V_i	13,000	13,000	13,000
Benefit in terms of deaths, £B_d	9,660,000	6,440,000	3,220,000
Benefit in terms of injuries, £B_i	5,376,000	3,584,000	1,792,000
Benefit, £B_{tot}	15,036,000	10,024,000	5,012,000
Cost	Scenario 1	Scenario 2	Scenario 3
Initial installation, £I	23.62	23.62	23.62
Maintenance and operation, £M	0.00	0.00	0.00
Interest rate, i	0.03	0.05	0.10
Years of operation, y	6.00	6.00	6.00
CRF, K	0.18	0.20	0.23
Cost, £C	4.36	4.65	5.42
Total cost of detectors in the UK, £	436,019	465,355	542,333
Cost benefit ratio scenario 1	34.48	22.99	11.49
Cost benefit ratio scenario 2	32.31	21.54	10.77
Cost benefit ratio scenario 3	27.72	18.48	9.24

Cost benefit calculation for caravans

There are estimated to be almost 1m caravans in the UK, so this has been used for the purpose of this cost benefit calculation [National Caravan Council, 2009].

Table 14: Cost benefit calculation for caravans

Caravans	High	Base	Low
Benefit			
Risk of death, R_d	7	4	2
Risk of injury serious, R_i	28	16	8
Risk of injury minor, R_i	112	64	32
Effectiveness at reducing death, E_d	1.00	1.00	1.00
Effectiveness at reducing injury, E_i	1.00	1.00	1.00
Value of death, £V_d	1,610,000	1,610,000	1,610,000
Value of injury serious, £V_i	172,000	172,000	172,000
Value of injury minor, £V_i	13,000	13,000	13,000
Benefit in terms of deaths, £B_d	11,270,000	6,440,000	3,220,000
Benefit in terms of injuries, £B_i	6,272,000	3,584,000	1,792,000
Benefit, £B_{tot}	17,542,000	10,024,000	5,012,000
Cost	Scenario 1	Scenario 2	Scenario 3
Initial installation, £I	23.62	23.62	23.62
Maintenance and operation, £M	0.00	0.00	0.00
Interest rate, i	0.03	0.05	0.10
Years of operation, y	6.00	6.00	6.00
CRF, K	0.18	0.20	0.23
Total cost of detectors in the UK, £	4,360,193	4,653,553	5,423,326
Cost benefit ratio scenario 1	4.02	2.30	1.15
Cost benefit ratio scenario 2	3.77	2.15	1.08
Cost benefit ratio scenario 3	3.23	1.85	0.92

Chapter 7

Conclusions

An overall review of the type and specifications of the detectors available on the UK market has been carried out. The main information gathered from this part of the study was the average price and lifetime of the detectors. It was also observed that the vast majority of the detectors commonly available conform to the latest European Standard, BS EN 50291:2001. Another point to be noted here is that all detectors (except one) have an end of life audible warning. This is important as this should encourage the uptake of replacement detectors.

The reliability of the new, electrochemical sensors is widely regarded to be excellent and cases of these detectors false alarming are extremely rare. If the detector installed is of the older type then it can be seen that false alarms can occur.

As a result of the extensive investigation into the fatality statistics regarding CO, a comparison has been made with those figures collected by the ONS and by CO-Gas Safety. These figures have been reasonably reconciled, with 35 deaths recorded by the ONS and 27 deaths recorded by CO-Gas Safety in 2007 relating to CO poisoning *not* related to suicide, suspected suicide, industrial sites or uncontrolled building fires. There will always be a modest discrepancy due to time delays regarding verdicts from coroners' courts.

The proportion of these deaths that have occurred due to natural gas and LPG, have been compared with the HSE RIDDOR numbers. The proportion of these deaths to have occurred from solid fuel, have been compared with the number of deaths recorded by the SFA. In both instances agreement is not unreasonable.

A detailed cost benefit analysis has been carried out and a cost benefit ratio calculated for the compulsory installation of CO detectors when fitting:

- gas and LPG appliances
- solid fuel appliances
- all combustion appliances within boats and caravans

Three levels of incident have been investigated, high, base and low. These show that it is:

- not cost effective to install a CO detector with *new* gas and LPG appliances due to the existing presence of a secondary safety system on these appliances
- it is cost effective for solid fuel, as these appliances (for technical reasons) do not already have a secondary layer of safety fitted to them, and whose flue gases are inherently high in CO

Although beyond the remit of this report, boats and caravans have been considered due to the high risk in these situations and it is therefore cost effective to install a CO detector in this situation.

Chapter 8

Recommendations

The installation of a CO detector within a dwelling containing a combustion appliance other than:

- a natural gas or LPG fuelled appliance that has full compliance with the Gas Appliance Directive
- an oil fired appliance other than using pressure jet burner

appears to be cost effective. This course of action is thus recommended. This is also consistent with other societal risks from an engineering perspective; most domestic/industrial equipment offering significant levels of risk are designed with one additional layer of safety (*eg* electrical appliances are earthed or double insulated, not both).

Due to the greatly increased risk in the event of a problem with the installation, all combustion appliances of any sort installed within a location likely to be of small volume and impervious, even with an air supply compliant with ADJ (*eg* boat, caravan) could similarly justify CO detectors.

It is the opinion of GaC that in those cases where a CO detector is cost effective, the detector fitted should be the sealed battery unit which was used as the base case detector for the cost benefit analysis.

Chapter 9

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