co+Impact

Determining the Impact of Carbon Monoxide Poisoning on the UK Population

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Dedication

This report is dedicated to all victims of carbon monoxide poisoning. It also would like to stress the plight that many British households have with other pollutants in their indoor air, which impacts heavily on their quality of life and in some cases may end their lives.

This research project and therefore this report, would never have happened in this form, if on the 5th of July 2011, Hazel Woodhams and Roland Wessling would not have taken an apparently cold and inactive BBQ grill into their tent for the night. Hazel died that night and Roland somehow survived. Since both he and Hazel were scientists, Roland made it his mission to bring more scientific research to the CO poisoning debate, so that more decisions can be based on proper scientific results and conclusions, rather than anecdotal data.

The co+Impact project was the first to be started in a series of projects that all aim to improve public safety with regard to carbon monoxide poisoning. While some of this further research may well be done at Cranfield University, this report invites, encourages, and urges researchers at other universities, R&D departments, or freelance, to do as much research in CO poisoning as possible. It cannot be stressed enough that only together we will make progress in our understanding of the problem CO, and how we can counteract its risks.

Acknowledgements

Jessica Bolton and Roland Wessling of the Carbon Monoxide Research ‘CORE’ group at Cranfield University, Shrivenham, would like to thank all those who assisted with this report over the last two years. For all your contributions, big and small, we are indebted to you. We extend special thanks go to a few generous individuals;

To Leigh Greenham, CoGDEM, for his constant support, and unsurpassable knowledge on all things ‘carbon monoxide’, much of this work and other enterprises could not have been done without your input.

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Everyone who has participated in a carbon monoxide Science and Technology Subgroup (CO^+SciTech) meeting during this work, especially Derrick Crump and Paul Harisson, for sharing their previous research and current insights into indoor air and CO.

And lastly, many, many thanks to the Hazel Woodhams Memorial Foundation for driving the research of the CORE group, and the Katie Haines Memorial Trust, for their passion and commitment to carbon monoxide awareness.

Project Outline

The co+Impact Project is a two-year study at Cranfield University, Shrivenham, and funded by the Gas Safety Trust. The aim of the project is to establish the impact of carbon monoxide poisoning on the UK population in a variety of environments. This would be done through a thorough literature review to establish the current state of knowledge on carbon monoxide and identify areas in which this knowledge is lacking. The study can then suggest future areas of research on carbon monoxide poisoning, as well as which areas should have priority, so that carbon monoxide research on the whole will have the biggest impact possible, on the protection of the public.

This report outlines some current themes in carbon monoxide poisoning research that are lacking in relevant knowledge and therefore do not provide the most accurate and reliable arguments for altering policy and the behaviours of the public. From this analysis, the project then suggests research that should be undertaken to fill these gaps. Furthermore, the work on this report has assisted in populating the web-based, freely accessible, 'CO Portal' hosted by the Gas Safety Trust, which provides a starting point for researchers undertaking projects in carbon monoxide poisoning.

The following pages summarise the research suggestions and recommendations made by this report, and it is hoped that they will be undertaken promptly by funders and researchers, such that knowledge in carbon monoxide poisoning can be advanced, for the protection of the general public, of the UK.

Recommendations

1. Due to the potentially high impact of chronic carbon monoxide exposure, research should be conducted into chronic low-level CO poisoning, its symptoms, its potential link to other common, chronic conditions, and on-going neurological sequelae.
2. More research into the levels of CO present in the home environment must be conducted to aid in the understanding of current numbers of low level occult exposures.
3. Studies using CO poisoning thresholds and categorising exposures should reconsider their definitions and exclusions to prevent missing data.
4. Current carbon monoxide alarm standards should reconsider evaluating their threshold CO concentrations for activation to keep up with WHO guidelines, research on low-level poisonings and knowledge on susceptible groups.
5. More research is needed into the numbers of individuals affected by carbon monoxide whilst staying in alternate/temporary domestic/leisure environments such as hotels, tents, caravans or boats.
6. The figures obtained from statistics should be coupled with data on travel rates and the types of CO incidents to determine the true impact of CO in leisure environments.
7. From this more successful and directed advice can be provided on actions to take, to at-risk groups, when in these settings.
8. Specific risks identified in leisure environments should be investigated, and safer ways of burning carbon-based fuels in such spaces developed.
9. More research should be conducted into the effects of increased airtightness on the plethora of toxins present in the domestic environment and their impact on the health of occupants.
10. Studies should be implemented to research the impact of increased airtightness in homes, on the levels of carbon monoxide for both chronic low-level concentrations and high-level acute CO leaks.
11. The preceding should be linked to the health impacts on the occupants for corresponding concentrations.
12. Further research should be provisioned to find methods to reduce the burden of indoor pollutants on occupants such as recommendations on activities and ventilation to reduce emissions and concentrations of pollutants.
13. The work of indoor air scientists should feed more regularly into policy in order to protect the public from pollutants produced indoors.
14. Studies that claim to be researching the number of deaths by preventable CO poisoning should attempt to accurately define their sample.

15. Non-fire related CO deaths should not be used as a blanket term for preventable CO deaths as it is misleading and excludes preventable cases.
16. Research in ICD code data utilisation should be conducted; specifically which fire codes are most often coupled with CO code data, and how ‘anecdotal’ or ‘media’ evidence would be coded by different individuals.
17. ICD-11 should attempt to include more CO codes like ICD-9, as ICD-10 is lacking, or should allow for more combination codes.
18. All data sets on carbon monoxide poisoning incidents should be collated and reviewed for more definitive suggestions of numbers of individuals affected.
19. Considering the difference in inclusion criteria for the pre-exiting data sets, any missing data should also be collected; relevant proposals should be drawn for their inclusion by currently included institutions or new organisations to undertake the work.
20. Groups and charities that have unique access to victims or carbon monoxide poisoning should be encouraged to collect more detailed qualitative information, to be added to the collaborative data set.
21. Whilst laws and regulations governing carbon monoxide alarms should be harmonised throughout the United Kingdom, there should be, in the meantime, an interactive repository for the laws on carbon monoxide alarm installation in the UK, which is easily accessible and informative for the public.
22. Alarm manufacturers should continue to make installation guides simple for the public to use effectively, and primarily to encourage their use.
23. There should be alarm standards for an alarm/system between domestic and industrial for smaller occupational premises.
24. If the optimal position for a CO alarm is on average a foot below ceiling height, then carbon monoxide alarms should be drop-tested from an equal height to this.
25. There should there be one advice line for CO such as 111 for the NHS.
26. Gas inspectors who are already required to ask about whether an individual has a CO alarm (without any legal connotations), should be able to install a CO alarm to optimal positioning and offer this as a service to those without an alarm.
27. A system dynamics study should be conducted to determine the current invested agencies in carbon monoxide poisoning prevention, and coordinate them and their impacts.
28. The study should engage with the current groups on CO to determine how they interact and impact each other and themes surrounding CO in order to create an agency map.
29. The agency map should be used to facilitate the inclusion of groups at meetings etc. and drive with direction and ease, research and policy in specific themes on CO.

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Glossary

Acute Poisoning	An isolated poisoning incident caused by a high concentration of carbon monoxide gas, culminating in severe symptoms.
AFAF	All Fuels Action Forum: a coalition of energy industry representatives, medical professionals, researchers, campaigners, and others, committed to tackling carbon monoxide poisoning in the UK.
APPCOG	All Party Parliamentary Carbon Monoxide Group: the leading forum for Parliamentarians to discover, discuss and promote ways of tackling carbon monoxide poisoning in the UK.
Chronic Poisoning	An on-going, long-term poisoning caused by a persistent low-level concentration of carbon monoxide gas with less severe symptoms.
CO	The chemical symbol for Carbon Monoxide: a poisonous gas produced during incomplete combustion.
COHb	Carboxyhaemoglobin: produced when carbon monoxide binds with haemoglobin in the blood.
Hb	Haemoglobin: the protein molecule in red blood cells that carries oxygen from the lungs to the body's tissues.
HBOT	Hyperbaric Oxygen Therapy: a medical treatment by inhalation of 100% oxygen in a total body chamber, where atmospheric pressure is increased and controlled, often used for treating decompression sickness, a hazard of scuba diving.
HSE	Health and Safety Executive: Great Britain's independent regulator for work-related health, safety and illness.
ICD	International Classification of Disease: the international standard diagnostic tool for epidemiology, health management and clinical purposes.
LPG	Liquid Petroleum Gas: flammable mixtures of hydrocarbon gases used as fuel in heating appliances, cooking equipment, and vehicles.
Occult Poisoning	An on-going, long-term poisoning caused by a persistent low-level concentration of carbon monoxide gas with less severe symptoms that are never correctly diagnosed as poisoning.
ONS	Office of National Statistics: the UK's largest independent producer of official statistics. Collects and publishes statistics related to the economy, population and society.

ppm	parts per million: concentration by volume of one part of a gas per million parts of air.
System Dynamics	An approach to understanding the nonlinear behaviour of complex systems over time.
WHO	World Health Organisation: a specialised agency of the United Nations that is concerned with international public health.

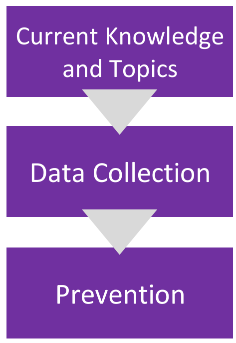
1 Introduction

The co+Impact report culminates the two years of work by the co+Impact project on carbon monoxide, and outlines the findings and suggestions of the study.

Carbon monoxide is a gas undetectable by any human sense and is released during the incomplete combustion of carbon-based fuels. When burnt in an enclosed space, these levels can build-up to be harmful to human health. Carbon monoxide binds to haemoglobin to form carboxyhaemoglobin and does so much more strongly than oxygen, which then limits the oxygen supply to major organs. At low levels this causes headaches, dizziness, and nausea, increased levels cause breathlessness and vomiting, and high levels coma and death. There are many potential threats of carbon monoxide production to the UK public including but not limited to boilers, fires, grills, BBQs and generators. It is often quoted that there are approximately 40 deaths and 200 incidents of CO poisoning requiring medical attention in the UK each year, though this is thought to be grossly underestimated for a number of reasons. The true impact of carbon monoxide poisoning on the UK population is unknown.

The co+Impact study was undertaken due to a recognised shortage of information on carbon monoxide poisoning, and a complementary, unintentional, lack of information sharing between agencies. Furthermore, the true impact statistically of carbon monoxides poisoning in the UK population, in a multitude of environments, is not known. A requirement of this project therefore was to review existing information of carbon monoxide poisoning to determine our current state of knowledge on CO and then identify gaps that could be rectified with research. The results of such directed studies would then improve the cases made for changes in behaviour of individuals, and the creation of policy, to protect individuals from the risks of CO. The intention of this report is to present the results of the co+Impact study and the recommendations for future research that have been made. It is anticipated that these studies will be taken on by funders and researchers in CO, such that the understanding of carbon monoxide can be improved.

This report presents the findings of the co+Impact study to determine the impact of carbon monoxide poisoning on the UK population, on a variety of relevant topics. The report covers areas such as CO alarms, the diagnosis of poisoning severity, and data collection, and future topics of increasing importance such as energy efficiency. From this, the report then suggests recommendations for research studies and actions for campaign and policy. In addition, it is important to note areas of CO poisoning prevention that are not included in this report. Apart from the installation and use of carbon monoxide alarms, there are other key actions that all households should undertake regularly to protect themselves. For example, to have their appliances checked annually, and to ensure that they are always used correctly and safely. The reason that the topic of annual boiler checks is not covered in this report does not reflect a lack of importance. However, aside from the fact that annual boiler checks and chimney sweepings should be more widespread, there is not much room for improvement here. Undoubtedly, the process by which occupants get their appliances checked could be reviewed, and in some small measure, improved. Research could be conducted to try to convince homeowners to utilise this measure more commonly, but within the co+Impact project, it did not appear necessary to scrutinise the process, and try to recommend drastic improvements. It has long been highlighted by many stakeholders that the current boiler checks could be expanded into a possibly mandatory, Home Safety 'MOT', and the spotlight is very much on government agencies and departments, to try to implement such a measure. If more research is necessary to prove the potential benefits of regular boiler services for public health, then this could be carried out swiftly and without much complication. Hyperbaric oxygen therapy (HBOT) is also not covered in this report. HBOT is an important subject, and possible treatment in CO poisoning, though its effectiveness is highly debated. It is due to this on-going debate, the countless other reviews on the subject and the further imminent reports, such as the Medical & Healthcare Professional sub-group of the All Fuels Action Forum report, that it has not been included here. The report however does suggest this as an area requiring significant further research both into its effectiveness, and other treatments.



The main section of this report is divided into three overarching chapters, each covering a distinct portion of the process for the research and prevention of carbon monoxide poisoning, and each containing several sections for relevant discussion. The first of these chapters (chapter 2), Current Knowledge and Topics (in CO poisoning), focuses on the knowledge base on carbon monoxide that affects research and prevention of poisonings. This information is rather fragmented and retained within groups, which is obstructive to the creation of policy and the protection of the UK population. This section of the co+Impact report details some crucial areas of information and themes on CO, that will be of increasing importance in the future, with regard to the prevention and treatment of the public. Chapter 3, Data Collection, outlines some of the current issues in data collection, affecting statistics on CO cases, and the figures on individuals exposed to CO. Data collection and subsequent analysis is an essential part of understanding carbon monoxide poisoning and prevention as it backs arguments of severity and provides epidemiological evidence of at risk groups which support and drive legislation to protect the population. Chapter 4, Prevention, is the final such chapter of this report and it concludes the path of research, combining knowledge and statistics to protect the public. Prevention can be considered the most important part of carbon monoxide poisoning discussion as it includes both front line defences in the home, the creation of policy and legislation at high levels, and all the awareness raising campaigns in-between. This chapter of the co+Impact report outlines important areas of CO poisoning prevention that improvement of such could facilitate the protection of the UK public from carbon monoxide.

2 Current Knowledge and Topics

While some elements of our current understanding of carbon monoxide poisoning are good, on the whole the state of knowledge is fragmented. It is not just characterised by a lack of knowledge, but also by misinformation that is often accepted widely as the status quo. What strong and sound information there is, is often contained within specific areas of research with little flow of information between groups. This can be inhibiting to the creation of policy and the protection of the public.

This section of the co+Impact report details some important areas of information on CO, and those themes that will be of increasing importance to the future safety of the UK population. These specific areas are crucial to our understanding of carbon monoxide poisoning, with regard to the prevention and treatment of the public. At the same time, they are, most decisively, lacking in breadth and depth of information, such that our ability to execute the above is at best, less effective and at worst, impossible.

The first section within this chapter will examine definitions of CO poisoning as compared to exposure, seriousness of poisoning, and acute and chronic cases is a significant topic for the diagnosis, treatment and statistical inclusion of carbon monoxide poisonings. While some definitions need a thorough review, others seem to work well for both research, and use in public health and policymaking.

Carbon monoxide poisoning incidents in leisure and recreational environments, although less frequent than those in domestic environments, lack adequate statistical analysis and epidemiological research, for successful creation of policy, and the advisement and protection of the UK population when away from the domestic realm, whether in the UK or further afield.

The topic of carbon monoxide poisoning in the domestic environment is of high importance due the vast amount of time we spend indoors, and in particular, in the home. Furthermore, the impact of such is set to change following the increases in airtightness and insulation, caused by the move towards more energy efficient housing. The possible presence of CO in the home is in itself significant, however, the potentially related direct and indirect health effects of CO in the home, are vastly unknown, and even less is known about the influence that decreased ventilation will have on the quality of indoor air, and carbon monoxide levels on occupants.

This section intends to highlight these issues and the areas in which information is lacking and suggests recommendations for actions and research that should be undertaken to better improve our understanding of CO poisoning for the purposes of prevention in the UK.

2.1 The Definition of Carbon Monoxide Poisoning

2.1.1 Introduction

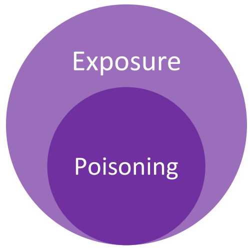
Poisoning is defined by Yari et al. (2011) as the absorption into the body of a substance to an extent that it becomes toxic and symptoms are experienced. Carbon monoxide (CO) is produced in the body naturally and carboxyhaemoglobin (COHb) occurs in non-smokers between 1% and 3% (Kao & Nanagas 2004), in smokers at about 10% to 15% just after smoking and 3% to 8% as a smoker's baseline (Ilano & Raffin, 1990). When CO is released by incomplete combustion it is inhaled, and binds with haemoglobin (Hb) producing COHb in potentially much greater quantities. This prevents the transport of oxygen around the body, causing some organs to starve of oxygen. The amount of CO absorbed by the body is based on ventilation, the duration of exposure and concentration of CO and O_2 (oxygen) present (Kao & Nanagas 2004). Fundamentally, more COHb produces more severe symptoms though this is highly variable. Less than 10% COHb will produce few if any symptoms. 10-20% will produce mild headaches upon exertion and 20-30% moderate headaches and nausea. 30-40% is likely to cause severe headaches, vomiting and fatigue. 50-60% will cause seizures and coma, and 70% and up will be fatal. (Harwood-Nuss et al., 2001 cited in Risavi et al., 2013).

% of COHb	Symptoms
<10	Few if any symptoms
10-20	Mild headaches upon exertion
20-30	Moderate headaches and nausea
30-40	Severe headaches, vomiting, and fatigue
50-60	Seizures and coma
>70	Fatal

Carbon monoxide poisoning can be broken down into several categories: duration of poisoning, COHb level of the victim and the symptoms experienced. However, this process is not in agreement for a number of reasons and could easily affect the data collected, the samples used in studies of CO poisoning and the treatment received by victims. More research needs to be conducted to determine a true pattern of symptoms in relation to COHb level and how CO poisoning should be treated. This would aid the recovery of victims, improve future research into poisoning effects and in addition, would help us to understand the true numbers of individuals affected by carbon monoxide poisoning both fatal and non-fatal.

2.1.2 CO Poisoning or Exposure

There is a difference between a case of carbon monoxide poisoning and an exposure, however, this is being defined inaccurately in some research studies, excluding true cases of carbon monoxide poisoning from research and statistics. The cases being excluded are usually low-level poisonings and these are already often missed and misunderstood. Excluding them from research could be affecting the figures for carbon monoxide poisoning and our knowledge on symptoms, diagnosis and treatment. More specific research needs to be conducted into these low level poisonings and such incidences should be included in all future research projects looking at the overall phenomenon of CO poisoning.



The difference between a case of poisoning and a case of exposure is defined by the National Poison Data System (NPDS) Coding Users' Manual (cited in Garrard, 2015, at the Washington Poison Center (US)), where to put it simply, "all poisonings are exposures but not all exposures are poisonings". An exposure is a case of actual or suspected contact with a substance by inhalation or absorption etc. regardless of toxicity. With regard to carbon monoxide, an exposure would be a case where a carbon monoxide leak in a flat has occurred, the residents are poisoned but the neighbours are also at risk of having been exposed, or the ambient levels experienced whilst walking through a town centre near traffic for example. A poisoning on the other hand would be a case where the contact concluded in adverse health effects, where the substance interfered with the normal function of the body. An example of this for carbon monoxide would be a child who falls into a coma from a BBQ being brought inside a tent for warmth, or a couple who have experienced nausea, shortness of breath, dizziness, vomiting and headaches for weeks due to their flue becoming blocked by a bird's nest. Clearly the difference between exposure and poisoning is rightly determined by the presence or not, of symptoms experienced by the victim, and a probable source.

Likewise, Mandal et al. (2011) outlined a case definition for carbon monoxide poisoning in the UK that could potentially be used for response and surveillance. This suggests that a possible exposure is based on a combination of low CO levels in air, symptoms, and a possible source, and a confirmed case would include a confirmed source, or higher CO levels in air. However, a confirmed poisoning must have symptoms, a COHb level over 5%, and a confirmed source, which when compared to a possible exposure and the difficulty in establishing a CO level in air in this context, significantly limits the cases that could be included.

Some studies on carbon monoxide poisoning also recognise a difference between poisonings and exposures, choosing to only include cases defined as poisonings and exclude those categorised as exposures. However, these are based not on the description provided above (on the presence of symptoms in the victim), but in the COHb level present in the victim. As discussed in the next section: the COHb level does not always correlate well with severity and therefore this should be based on the symptoms experienced by the victim. We know little of low-level, on-going poisoning cases (discussed later) and thus it is not advantageous to exclude them from research. This suggests that true carbon monoxide cases are being excluded from statistics and research despite the victims suffering with symptoms of CO poisoning. This is extremely likely to affect the statistics on the true numbers of victims of carbon monoxide poisoning and restricting our knowledge on carbon monoxide.

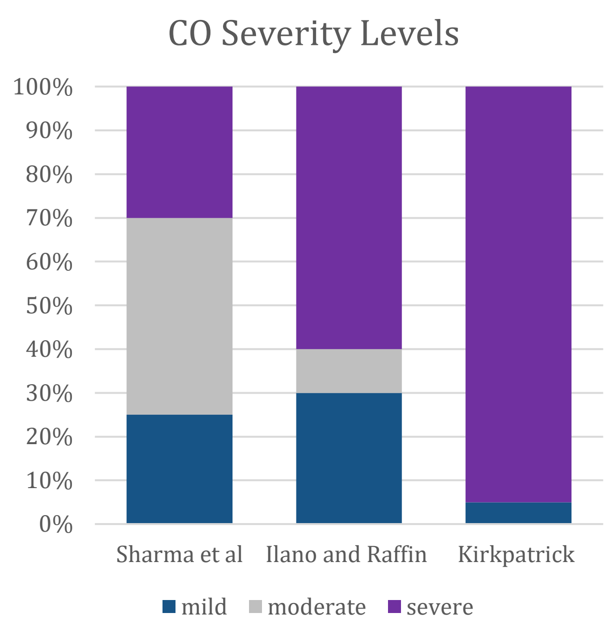
On the other hand, Decker (2016) states that the state based CO surveillance system in Maine, has a number very detailed criteria including but not limited to, smoking status, COHb level, and clinical evidence, to determine their case designation (confirmed/probable/suspect/ exposure) of each incident. This, coupled with the broad initial criteria for reporting and the presence of an interview section to gather more detailed information on the incident, leads to a very thorough and informative surveillance system on carbon monoxide.

Low-level poisonings represent a significant proportion of all carbon monoxide poisonings and yet are the least understood and high impacting when the UK public is considered. These true cases however are being excluded from some research studies and statistics on the basis of an inaccurate definition of exposure. It is understandable for studies to concentrate on either high or low level CO poisoning research as they differ considerably (discussed later), but exclusion from studies that investigate the number of people affected by CO introduces significant errors in our figures. Low-level cases should be included in statistical research as they constitute true poisonings and further research should be conducted to establish what these true figures are.

2.1.3 CO Poisoning Severity

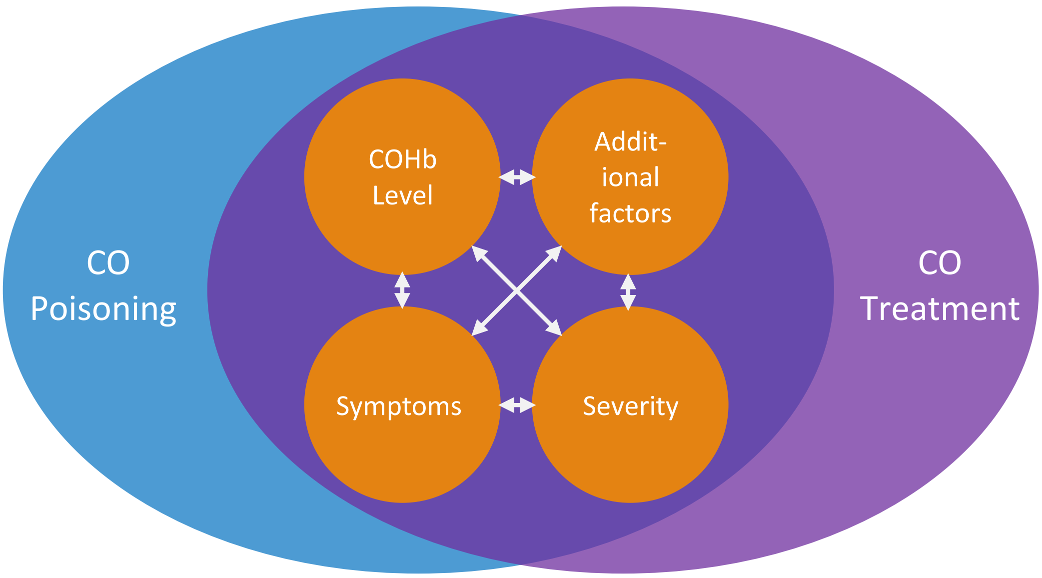
The severity of poisoning cases is often categorised based on the COHb level of the victim and used for inclusion in and exclusion from research studies as well as statistics and treatment methods. The severity of symptoms are also used, however not to categorise cases, but more to discuss the spectrum of symptoms from mild headaches and nausea to severe coma and seizures. However, there is little correlation between concentration of COHb and the severity of the symptoms experienced by the victim. Assigning arbitrary cut-off points in the spectrum of COHb levels and symptoms is not advantageous to research, is based on weak correlations, and affected by additional variables. Furthermore, it can affect the treatment the victim receives which could be detrimental to long-term recovery. More research is required to understand the links between symptomology, COHb levels, additional poisoning factors and CO treatment.

There are many variable figures and thresholds used in studies to determine severity of poisonings and inclusions in studies. With regard to COHb levels there are threshold figures that are defined by the Council of State and Territorial Epidemiologists, US, to categorise cases for inclusion in research and to determine the treatment of victims. They suggest that COHb levels of 12% or more constitute CO poisoning cases (Iqbal et al., 2012). Sharma et al. (2014) suggest that COHb levels above 25% are severe poisonings and above 70% would be a risk of fatality. Ilano and Raffin (1990) for example suggest that treatment requirements be divided into three categories based on severity; mild, moderate and severe. Where mild included cases with COHb levels less than 30% and where there is unlikely to be any signs of reduced cardiac output but headaches, nausea and vomiting may be present. Moderate poisoning is 30-40% COHb and severe is cases over 40% COHb affecting the cardiac, pulmonary and central nervous system. However, Kirkpatrick (1987) suggests that COHb levels of less than 5% could still be a poisoning case and even severe symptoms and comas have been seen in patients with a COHb level of 0%.



The symptoms of carbon monoxide poisoning are very variable, do not correlate well with COHb levels (Kirkpatrick, 1987; Ilano & Raffin, 1990; Green et al., 1999; Prockop & Chichkova, 2007; Risavi et al., 2013; Roderique et al., 2015), and not all patients develop the same set of symptoms when exposed to CO. Furthermore, there is no correlation between base COHb levels in a patient and their response to exposure (Kleinman et al 1989). For example, symptoms start in 80% of people with a headache and symptoms worsen as COHb levels rise (Chavouzis & Pneumatikos, 2014). Headaches are present in both acute and chronic exposure (discussed later) but there is no correlation between COHb levels and the pain intensity of the headache (Hampson & Hampson, 2002, cited in Prockop & Chichkova, 2007). Kao and Nanagas (2004) and Green et al. (1999) suggest that there must be another reason other than hypoxia for COHb not correlating with severity of symptoms, such as toxicity at cell level. One of the many reasons for the variability in the symptoms experienced by victims of CO poisoning compared to their COHb level are patient specific factors (Roderique et al., 2015) such as age (Risavi et al., 2013). The health status of the victim should be taken into account (Chiew and Buckley, 2014) as CO poisoning can exacerbate pre-existing conditions (Risavi et al., 2013). For example, pregnancy can already cause anaemia and elevated COHb levels which will be made worse by CO intoxication (Risavi et al., 2013). COHb levels of over just 10% should be recognised by sensitive individuals (Green et al., 1999). In addition, smokers also have elevated COHb levels that will need to be interpreted accordingly (Varon et al., 1999). Furthermore, all individuals have a risk of suffering from delayed symptoms of carbon monoxide poisoning (Prockop & Chichkova, 2007), however, seriousness and COHb levels are not predictive in delayed symptoms either (Chavouzis & Pneumatikos, 2014).

COHb levels can be an inaccurate method for determining carbon monoxide poisoning severity in the living as they begin to reduce once an individual has been removed from a source, whereas levels are more stable in fatal cases. The COHb levels of the victim need to be measured as soon as possible so the true level is known before O_2 is administered or they travel to hospital for example (Kao & Nanagas, 2004) as COHb will begin its half-life (4-6 hours) after removal from the source (Varon et al., 1999) and this is accelerated by O_2 administration (75-35 minutes). This causes further mismatch between COHb level and symptomology therefore making COHb levels an unreliable method of CO poisoning severity determination. Varon et al. (1999) and Chiew and Buckley (2014), suggest that COHb level of the victim can be used as a rough guide to severity classification, but it is misleading and not reliable or appropriate; severity diagnosis should focus on the symptoms of the patient. The severity of the poisoning event should be based more on the duration of exposure and the concentration in the air (Sokal et al., 2002 cited in Vreman et al., 2006) and the symptoms experienced by the victim, regardless of COHb level should be the critical factor in the diagnosis of severity (Myers, 1998).

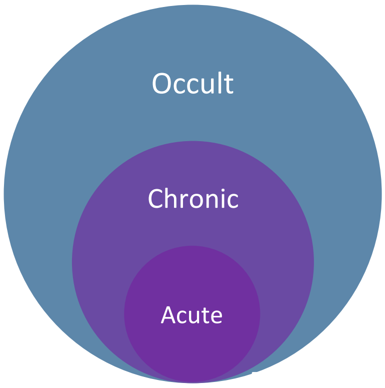


Ilano and Raffin (1990) suggest that severity graded by COHb is misleading as to clinical requirements, and could negatively affect the treatment method the victim receives. Nevertheless, COHb levels are often used as a criterion for diagnosing the severity of a poisoning incident in order to establish whether hyperbaric oxygen therapy (HBOT) should be administered. Although the useful effects of HBOT on CO poisoning have not been confirmed either way, it is often used in the treatment of CO poisoning. As with the severity of poisoning COHb levels, there is no consensus on the minimum COHb level required for HBOT (Varon et al., 1999) or even any other reliable criteria for selection patients to receive it (Kao & Nanagas, 2004). Commonly though a mixture of COHb levels, symptom severity, and prior medical conduction such as coronary artery disease (CAD) or pregnancy are used to determine patient suitability. These include a significantly high COHB level (40%), coma or loss of consciousness at any time, pregnancy and neurological/pulmonary/cardiac problems prior, or due to CO (Kao & Nanagas, 2004; Satran et al., 2005). The Undersea and Hyperbaric Medical Society, US, suggests anyone with severe symptoms or pregnancy, regardless of COHb level should receive HBOT as treatment for CO poisoning (Varon et al., 1999).

It is clear that dividing up the spectrum of COHb levels arbitrarily to reflect the severity of a poisoning incident is counter-productive, as COHb levels do not adequately correlate with the symptoms a victim will experience. There is no agreed method of dividing incidents and too many additional variables affecting these correlations. Dividing poisonings based on severity by COHb level may lead to true poisoning cases be excluded from research and statistics resulting in the loss of valuable information.

2.1.4 Acute, Chronic and Occult

Carbon monoxide poisoning can produce both acute and chronic effects (Varon et al., 1999; Risavi et al., 2013). This is a common way of dividing CO poisoning incidents; they are different, such that they can be prevented, treated and diagnosed in different ways. Unlike the severity of poisoning cases, acute and chronic are based on duration and concentration of exposure. These differences can be used to guide specific research, especially into chronic poisonings, which make up the largest portion of all and especially undiagnosed poisoning cases, and are the most variable, misunderstood and high impact poisonings.



Wright (2002) provides clear definitions of acute, chronic and also what he labels ‘occult’ carbon monoxide poisonings. Acute CO poisoning is defined as a case that has come to immediate attention of practitioners following exposure, usually of a high concentration of CO. Wright (2002) defines a chronic poisoning as a case in which the victim is exposed on more than one occasion to lower CO levels; they are likely to experience mild symptoms that may eventually come to the attention of a doctor. Occult (lat: ‘occultus’ meaning *clandestine*, *hidden*, *secret*) poisoning on the other hand indicates a case that never comes to the attention of a medical practitioner. This is usually a chronic poisoning case where medical attention is not sought or is the illness is misdiagnosed, or it could be an acute fatality, where the cause is never determined to be CO (Wright, 2002). Chronic cases are often not lethal in adults, although they can be fatal for a child, as they are more susceptible to CO (Kao & Nanagas, 2004).

However, it is important to note that as different as these types of poisonings may appear, they can be combined in one victim (Townsend & Maynard, 2002). For example, occult and chronic low-level can occur for a long while, affecting victims with mild symptoms. It may then transpire that a change in air flow from building works, obstructions or even just the use of heating appliances at the beginning of winter could accelerate the situation, causing a large amount of CO production and an acute poisoning incident, with more serious symptoms and a higher COHb level. Duenas-Laita et al. (2001) found evidence of this in their study where 19.2% of their CO poisoned patients recalled having headaches on the days before they visited the emergency medical department. This indicates a chronic exposure culminating in a need for emergency medical attention; the suggestion of prior chronic poisoning may then suggest difference in treatments and risks of on-going complications (Duenas-Laita et al., 2001). In these such cases, the symptoms can be difficult to determine from each type of poisoning and any pre-existing medical conditions (Townsend & Maynard, 2002).

With severity of CO poisoning, as discussed previously, there is little correlation between acute and chronic CO poisoning and a victim's COHb level (Wright, 2002). COHb level cannot be used to diagnose whether a patient is suffering the effects of chronic or acute carbon monoxide poisoning (Myers et al., 1998), a diagnosis should be based on the concentration of CO in the air, the duration exposure and the symptoms suffered by the victim. There is a poor correlation between COHb and symptoms for both acute and chronic (Wright, 2002) and the symptoms experienced in chronic and acute poisonings are variable however, in acute cases, COHb roughly correlates with symptomology (Varon et al., 1999). As mentioned before, in smokers these correlations between poisoning categories, COHb level in the victim and symptoms are even more variable and should be diagnosed accordingly (Wright, 2002). Despite the lack of correlations observed, acute and chronic are commonly used and well defined differences in poisoning cases. They are not defined by COHb levels, which do not correlate well (unlike CO poisoning severity). These two categories of poisonings should continue to be used as they have different epidemiologies and symptomologies, that can be used to drive research in specific areas, to ultimately protect the public from two quite different dangers.

Acute and chronic CO poisoning have different symptoms, treatments and clinical outcomes. They are often researched separately due to such differences, however much more is known about acute carbon monoxide poisoning than chronic (Kirkpatrick, 1987; Wright, 2002). Less is known about the chemical and health effects of continued low-level exposure in chronic CO poisoning and there have been no controlled studies (Myers et al., 1998), with research focussing on the short-term effects in experimental settings (Townsend & Maynard, 2002). Furthermore, the long-term effects of both acute and chronic carbon monoxide poisoning are not well understood (Green et al., 1999).

The symptoms of chronic carbon monoxide poisoning are mild, variable and non-specific (Townsend & Maynard, 2002. Headaches, nausea and vomiting for example (Varon et al., 1999), are often mistaken for other illnesses such as flu and food poisoning; this makes chronic exposures hard to diagnose (Myers et al., 1998). These symptoms are often not enough for an individual to even require or seek medical attention at an emergency department or a hospital admission (Wright, 2002). Due to high levels of un/misdiagnosed cases true numbers of misdiagnosis are still unknown (Wright, 2002) and the extent of chronic and occult exposure in the UK population is unknown (Wilson et al., 2015). It is estimated that in one year about 1000 people will seek medical attention due to the effects of low-level carbon monoxide poisoning (Hampson & Norkool, 1992 cited in Varon et al., 1999). Carbon monoxide poisoning can be treated as a pyramid of disease or 'iceberg' where the small tip represents less common but overt and diagnosed, acute poisonings and the base of undetermined size reflects the occult, chronic low-level and acute poisonings hidden beneath the surface (Wright, 2002). Despite the predicted amount of chronic cases, little is known about low-level poisonings, and finding the true number of low-level poisonings when they are rarely diagnosed is challenging and requires more research. Cranfield University and Public Health England (PHE) will soon be conducting research into coroners' data on COHb levels in all deaths in order to determine the extent of occult carbon monoxide poisoning. It is important for more research to be conducted in to the effects of chronic low-level carbon monoxide poisoning as the impact on the UK population is not one of just the high numbers of potential victims but also of the severity of symptoms and likelihood of prolonged effects (Townsend & Maynard, 2002). Ilano and Raffin (1990) also suggest that the strong affinity of CO to Hb means that even a low-level poisoning is a case of severe toxicity. However, there are ethical issues involved in carbon monoxide poisoning experiments, especially with humans (Townsend & Maynard, 2002).

One aspect in this context and that has not been mentioned yet, is the environment in which poisonings take place. The home is an especially important factor in the understanding of undiagnosed, chronic low-level carbon monoxide poisoning, as we spend most of our time there, but the levels of background carbon monoxide present in the home, in the UK, are still unknown (Green et al., 1999). Prolonged exposure for days to months to low concentrations of CO can affect the brain, with short-term recovery when away from the toxic environment (Townsend & Maynard 2002). It is possible that many members of the public are affected by CO in the home, therefore the effect this has on the public's heath should be known (Townsend & Maynard, 2002). Considerably more research needs to be conducted on the effects of ambient CO in UK homes (Wright, 2002). Furthermore, in light of our lack of understanding and the lack of correlations between COHb, chronic poisoning, and symptoms expressed, even if COHb levels are normal, if symptoms are present the victim can still be affected by CO poisoning so they should be encouraged to get their home environment in general and specifically their appliances checked.

Acute and chronic poisonings are a useful, relatively non-contradictory way of dividing CO poisoning incidents for research, treatment, diagnosis and prevention. Chronic poisonings, although experienced at low concentrations of carbon monoxide, can be considered to be the most severe and have the biggest impact on the UK population. This is due to the insidious and occult nature of undiagnosed and misdiagnosed occurrences, the risk of long-term medical issues, and the greater numbers of individuals at risk. However little is known about chronic CO poisoning compared to the dramatic effects of acute poisonings; links to other chronic conditions, such as asthma, dementia or Parkinson's disease, cannot be entirely excluded at this point. Even conditions, such as strokes, which involve reduced oxygen supply to the brain, maybe influenced by chronic CO poisoning. Significantly more research is needed into the symptoms of chronic poisoning by carbon monoxide, the long-term health implications, and the ambient CO levels present in UK homes.

2.1.5 Recommended CO Levels by the WHO and the CO Alarm Standards

There is much contention about the carbon monoxide concentration at which people will start to experience symptoms or the concentration that CO becomes life threatening. Symptoms are highly variable as to COHb level and symptoms can be experienced at very low CO concentrations even for normal healthy individuals. However, there are many populations where lower levels of CO are detrimental. The World Health Organisation (WHO, 2010) describes the maximum CO levels that could be experienced for a certain duration to prevent the build-up of dangerous levels of COHb (5.68ppm for 24 hours) however carbon monoxide alarm standards (BSI, 2013a) state a much higher CO concentration for alarm activation (50ppm for 90 minutes). More research is needed on the levels at which CO can be harmful to humans especially the more susceptible and the effects of low-level chronic poisoning.

Typical symptoms for a healthy individual are variable, non-specific and do not correlate well with a victims COHb level. However, many studies discuss a basic exposure-response relationship between COHb level increase and an increase in the severity of symptoms. As previously discussed, levels of COHb less than 10% will produce few if any symptoms, about 10-20% will produce mild headaches upon exertion, and 20-30%, moderate headaches and nausea. 30-40% is then likely to cause severe headaches, vomiting and fatigue, 50-60% COHb will cause seizures and coma, and 70% and up, will be fatal. (Harwood-Nuss et al., 2001 cited in Risavi et al., 2013). The median level of COHb causing death from CO however is suggested to be just 53-55% (WHO, 2010).

Young children, the elderly, pregnant women and those with suffering chronic pulmonary or cardiac illness are the most susceptible to carbon monoxide poisoning. They are most susceptible in uptake and effect, the least likely to be able to take preventative action, and the least likely to be diagnosed in time and given effective treatment (Wilson et al., 2015). Statistics suggest that acute, non-fatal CO poisoning in children less than four years old is only 8.2 in 100,000 which is the highest of all adult and children groups (CDC, 2005 cited in

Mendoza & Hampson, 2006). With regard to pregnant women, the foetus is highly susceptible to carbon monoxide, which crosses the placenta readily, reaching toxic levels faster, and furthermore loses CO slower than the mother during treatment (Guzman, 2012; Kaos & Nanagas, 2004). These individuals will begin to feel the effects of carbon monoxide at much lower levels than normal healthy individuals and therefore should be more aware of CO levels and take appropriate actions for prevention and treatment.

The World Health Organisation (WHO, 2010) outlines the suggested maximum levels of indoor CO that could be experienced and should not be exceeded, with those members of the public suffering cardiovascular disease in mind. These levels are 81.1ppm for 15 minutes, 28.4ppm for 1 hour, 8.11ppm for 8 hours and 5.68ppm for 24 hours (WHO, 2010).

In contrast, the British alarm standards (BSI, 2013a) set a concentration of over 50ppm for 90 minutes before activation of the audible alarm. They suggest that there is no need for a CO alarm activation prior to 50ppm as the COHb level of the occupant would not reach a level high enough to experience severe health effect. Some carbon monoxide alarms have a visual digital display that activates at a lower CO concentration so the concentration can be read and acted upon in the case of susceptible groups. However, this does nothing to alert the owner to the presence of potential harmful levels of carbon monoxide gas. An alert system on the other hand with a reduced CO activation level would make low-level poisoning appear to be an emergency, which it is not. However, a different alert system (tone and volume) could potentially be used to alert to low CO levels its potential threats. The alarm standards do recognise the susceptibility of specific groups to carbon monoxide poisoning (BSI, 2013b) however they fail to protect these individuals, and other from the effects chronic low-level exposures that impact our population.

The WHO outlines the maximum CO levels that could be experienced for a specified duration to prevent the culmination of harmful levels of COHb in individuals, considering both the effects of acute and chronic poisonings. However, carbon monoxide alarm standards utilise a much higher minimum carbon monoxide concentration for alarm activation, considering only the effects of acute poisonings. Symptoms of CO poisoning, as demonstrated, are highly variable as to the COHb level of the victim and serious symptoms can be experienced at very low CO concentrations, even for normal healthy individuals. Furthermore, there are many populations such as the elderly, young, ill and pregnant where lower levels of CO are detrimental. More research is needed on the levels at which CO can be harmful to humans especially the more susceptible and the effects of low-level chronic poisoning and alarm manufactures should consider altering the alarm standards for a mandatory, separate activation at lower CO concentrations.

2.1.6 Conclusion

The way that carbon monoxide poisoning incidents are categorised for research and statistics can affect the information that we glean from such projects and the treatment that victims then receive. It is clear from this discussion that the presence of significant variables, and considerably weak correlations, make some methods of categorisation better than others. Exposures and poisonings are inherently different however the misuse of the term exposure has led to the exclusion of many low-level poisoning incidents in research and individuals suffering symptoms of carbon monoxide poisoning. The use of the categories 'exposure' and 'poisoning' could still be a reasonable way of separating poisonings from non-poisonings, but should be based on symptomology not COHb. Much like this argument, poisonings should not be divided on the basis of severity using COHb levels of the victim. Categorising incidents is useful for treatment and research however the correlations between symptoms and COHb are not strong enough and the consensus between researchers lies to the side of division by symptomology again, unless more accurate way of measuring COHb can be found. Finally, a truly useful way of dividing cases by duration and concentration of exposure lies in chronic verses acute poisonings. The significant differences between these with regard to prevention, treatment, outcomes and diagnosis etc. suggest that they are necessary divisions for research and statistical analysis. From this examination of CO poisoning levels it has also become apparent that the symptoms experienced by individuals are sufficiently variable and non-correlating with COHb that carbon monoxide alarm standards should be brought into line with what we now know about low-level and patent-specific clinical manifestations. Much future research is suggested to further understand the issues outlined here.

2.1.7 Recommendations

- Due to the potentially high impact of chronic carbon monoxide exposure, research should be conducted into chronic low-level CO poisoning, its symptoms, its potential link to other common, chronic conditions, and on-going neurological sequelae.
- More research into the levels of CO present in the home environment must be conducted to aid in the understanding of current numbers of low level occult exposures.
- Studies using CO poisoning thresholds and categorising exposures should reconsider their definitions and exclusions to prevent missing data.
- Current carbon monoxide alarm standards should reconsider evaluating their threshold CO concentrations for multiple activations to keep up with WHO guidelines, research on low-level poisonings and knowledge on susceptible groups.

2.2 CO Poisoning in Leisure Environments

2.2.1 Introduction

Carbon monoxide poisoning in leisure or holiday environments is a broad and sparsely understood topic due to the variety of possible locations, causes of incidents, and the lack of statistics and research on such cases. Incidents in leisure environments include both domestic and commercial premises such as,

- B&Bs and Hotels,
- boats,
- tents and caravans,
- restaurants,
- and attractions,

both in the UK and abroad. Carbon monoxide poisoning in such environments may not have a large impact on general UK CO population due the little amount of time and frequency which we spend in one such location. Weaver and Deru (2007) agree, stating that the risk of CO poisoning from a 1-night stay to an individual guest in any leisure environment is small, however the accumulated lifetime risk to individuals who travel frequently would be higher. The issue is covered here as a matter of principle in that these cases do occur, and are just as detrimental as those in domestic environments. Therefore, they deserve the same coverage of research and prevention efforts to protect individuals when they are away from home.

2.2.2 The Issue of Incidence and Prevention

One of the issues with regard to leisure environment CO poisonings is the lack of data available to back research and prevention campaigns. Tam et al. (2012) discussed the results of the Committee for Local Governments (CLG) study (2009) on carbon monoxide detector provision, which suggested that the Office of National Statistics data on CO poisonings does not distinguish the type of home in which the incident occurred. The CLG study (2009, cited in Tam et al., 2012), had to rely on other data sets for this information, namely the Carbon Monoxide and Gas Safety Society (CO-Gas Safety) which it suggests highlights a disproportionately high incidence of cases in caravans and boats compared to homes. It seems unlikely that so many incidents occur in theses environments as compared to homes. This could be due to the media influence on initial collection of this data set. However, it strongly suggests that it is difficult to access this specific data and therefore, to determine the impact of carbon monoxide poisonings in leisure environments on the UK population.

Furthermore, very few studies have been conducted into carbon monoxide poisonings in recreational and non-domestic environments; this limits our understanding of *cause and effect* and therefore how we can protect the public. Silvers and Hampson (1995) did examine incidents of CO poisonings on recreational boats in the USA that occurred between 1985-1994. They found 27 incidents where 39 people were poisoned severely and acutely, needing emergency medical attention. The cause of CO release was the engine in 21 incidents, and heaters and generators in the other 6 cases. They predict that is set to rise due to the increase in interest in boating, and suggest that boats carry audible carbon monoxide alarms.

On the other hand, several studies have been conducted on CO emission from stoves in tents; however, they focus specifically on short-term use at arctic temperatures. Thomassen et al. (2004) investigated if burning a cooking stove inside a tent is a potential health hazard. Volunteers used stoves in tents for 120-minute sessions, after just 30 minutes, CO levels in the tent were between 350 and 500ppm. When the stoves burnt with a kettle the CO emission rose further. The results indicated that kerosene camping stoves produce significant amounts of CO when used in a tent. None of the subjects had any symptoms of CO poisoning, such as headache or dizziness, however all experienced a significant increase in heart rate. A hike or a military maneuver over a period of days could therefore lead to a dangerous rise in COHb and chronic poisoning. These studies on the use of stoves in tents represent an intentional tradeoff made by users between CO poisoning and freezing temperatures when camping in arctic conditions, and are used for a short time. But they do not represent longer use of stoves by campers that are unaware of the dangers of CO. The use of volunteers in such experiments, with concentrations at such high levels, appears somehow reckless, and is not condoned by the co+Impact researchers. Far too little is known about the long-term effects of low or high level CO poisoning on the human system, to enter into such volunteer-based research.

Mcleod (2013) experimented with the use of charcoal burning inside tents for heat and concluded that CO was always released at dangerous levels, even at lower temperatures when charcoal was burning out, and that the tent caused levels to accumulate. More research like this is required to assess the impact of CO to the general UK public when in recreational environments. Research has started into CO release from solid, carbon-based fuels, and how its impact within small spaces (such as boats, caravans and tents) can be counteracted, at Cranfield University in the form of a 3-year PhD project.

Weaver and Deru (2007) conducted a thorough analysis of poisonings in hotels and motels in the USA. They found that faulty, room-operated furnaces or boilers used to heat rooms or provide hot water caused 66% of incidents, and boilers, pool heaters, and spas caused 24%. Some occupants were poisoned in their rooms from inadequate venting and leakage of CO from the boiler into the guest rooms, 7% had CO enter from outdoors, and in 3% of incidents, the source of CO was unidentified. It is clear that hotels can be a significant cause of CO poisoning but statistics in the UK are not available. Furthermore, these deaths are out of the control of the occupants as they are not responsible for the malfunctioning appliances, and it would be more than reasonable to reduce these incidents through use of carbon monoxide alarms.

Keshishian et al. (2012) examined the impact of carbon monoxide poisoning in restaurants and their effect on adjoining domestic premises. They concluded that there is a risk to workers I these environments with charcoal grills having the greatest risk. The CO produced can easily travel between establishments, and there is no legal requirement for restaurants to install CO alarms, though it is recommended by the Health and Safety Executive.

There are two main options for the protection of individuals with regard to carbon monoxide poisoning in leisure environments, either the provision of carbon monoxide alarms in alternate dwellings, or the convincing of the public to bring CO alarms on holidays for their own protection. Weaver and Deru (2007) in their study on CO poisoning in hotels discuss the propensity for the reduction of incidents with the provision of alarms by the hotel. Several US states have legislation requiring CO alarms in hotels including Alaska, Connecticut, Massachusetts, Minnesota, New Jersey, and Vermont, however no state requires alarms in all guest rooms. Guests at could be protected from CO poisoning by installing a CO alarm in every guest room, though the estimated cost of this (considering the number of guest rooms in the US as 4.4 million) could exceed $100 million. The installation cost is then compared against the risk for CO-related mortality and morbidity, the monetary awards for damages to guests, and enforcing this legislation.

Alternatively, holidaymakers could be convinced to bring their own CO alarms with them for safety, which would cover all locations, at times of high risk. However, the uptake of CO alarms in homes in the UK is only approximately 22%, therefore the propensity for this as an option, is low. Furthermore, convincing individuals to get CO alarms for their homes is hard enough (discussed later), without the additional task of convincing individuals that they need to bring it with them on holiday. Being on vacation causes a different mind-set in individuals where dangers become less obvious and important, therefore the public needs to be convinced more than once about the dangers of carbon monoxide poisoning (APPCOG, 2015). This makes the issue of CO poisoning in recreational environments and the protection of the public a challenging battle.

2.2.3 Conclusion

Carbon monoxide poisoning incidents in leisure environments such as hotels, tents, restaurants and caravans are unlikely to have a significant impact on the UK population due the infrequency and little amount of time with which we spend in one such environment. However, these cases do occur and are just as detrimental as those in domestic environments. Therefore, they deserve the same coverage of research and prevention efforts to protect individuals when they are away from home. Carbon monoxide poisoning in leisure or holiday environments lacks available statistics and research to determine the true extent of this issue and therefore the adequate means to back legislation and campaigns to protect the public from CO in these situations. More research needs to be conducted in this area, for statistics, epidemiology, and health effects, not just to fill gaps in knowledge, but to provide an initial knowledge base lacking here in the UK.

2.2.4 Recommendations

- More research is needed into the numbers of individuals affected by carbon monoxide whilst staying in alternate/temporary domestic/leisure environments such as hotels, tents, caravans or boats.
- The figures obtained from statistics should be coupled with data on travel rates and the types of CO incidents to determine the true impact of CO in leisure environments.
- From this more successful and directed advice can be provided on actions to take, to at-risk groups, when in these settings.
- Specific risks identified in leisure environments should be investigated, and safer ways of burning carbon-based fuels in such spaces developed.

2.3 Energy Efficiency and Carbon Monoxide in the Domestic Environment

2.3.1 Introduction

In the UK we spend approximately 90% of our time indoors, and 70% of our time in the home environment (Brown et al., 2010; Yu & Crump, 2010; Das et al., 2012) and there is potential for the population to be exposed to a myriad of toxins that are harmful to health. However, the importance of our indoor air quality has received little recognition (Brown et al., 2010). In reality, the main focus is on outdoor air, which has lower concentrations of toxins (Sharpe, 2004; Milner et al., 2015) and has little effect on indoor pollutant concentrations, apart from setting a base-level.

This subject has reached a new level of importance in recent years. Due to the desire and obligation to reduce carbon emissions in the UK; homes have become, and will keep becoming more airtight, reducing the ventilation in homes and 'locking-in' pollutants. Few studies have examined the impact of increased airtightness on pollutants in the domestic environment, and their impact on sort-term and/or long-term health of the UK population (Milner et al., 2015; Sharpe et al., 2015).

Even fewer have examined the impact that increased airtightness has on carbon monoxide levels in the home. Despite this, the topic is raised regularly as a contributing factor in carbon monoxide poisoning even though it has little scientific research backing, and other toxins are used as proxies. While CO cannot be treated in isolation when it comes to the indoor air quality debate, this report will nevertheless examine the specific part CO plays.

2.3.2 CO in the Domestic Environment

Carbon monoxide is always being produced in any domestic environment that uses combustion appliances, which are particularly common in UK homes. As long as the appliances works well and has sufficient ventilation, CO levels will not be dangerous to occupants. However, considering the deadly nature of CO, the fact it cannot be sensed by humans, and the amount of time western populations spend in their homes, CO is the most dangerous pollutant in indoor air, and therefore it is significantly important to monitor (Raub et al., 2000; Raw et al., 2004).

Afsset (2007) quotes European Commission, 2005 research that states that within the global population, 80% of an individual's daily exposure to CO occurs in enclosed areas, and 6% occurs outdoors. Although outdoor CO levels do influence indoor levels, the major contributors to indoor concentrations are sources such as cookers and heating systems burning fuels. Other factors that can also affect indoor levels include tobacco smoke, the presence of an attached garage, and living near heavily trafficked roads (Green & Short, 1998; Harrison & Holmes, 2001).

Poorly installed, under ventilated and malfunctioning appliances, and accidentally blocked flues, however, are the most likely causes for increased indoor CO levels (Crawford et al., 1990; Green & Short, 1998; Harrison & Holmes, 2001; Tam et al., 2012). At least 39,000 homes in the UK may have a faulty appliance, and a total of approximately 200,000 homes may have the potential for carbon monoxide production from a gas appliance (Tam & Crump, 2009). Faulty/unvented combustion appliances have measured CO in excess of 100ppm, which is estimated to result in COHb levels of greater than 10% after eight hours (Raub et al., 2000). Over 22 million homes in the UK (just over 80%) use either mains gas or liquid petroleum gas (LPG), which bring with them, a risk of CO poisoning. A study in Spain (Morales et al., 2009 cited in Tam et al., 2012) found that early life exposure to faulty gas appliances was a risk factor for impaired cognitive function and development. Croxford (2007) found that gas fires were the most frequently problematic appliances with regard to carbon monoxide production, and even Combi Boilers can produce significant amounts of carbon monoxide when the flue is just partially blocked, and the air supply is not really inhibited (Hill & Pool, 1998 cited in Hill & Pool 2001). Traynor et al. (2012) suggest that unvented gas fire space heaters produced CO, and the emission rates of CO were varied during use and did not remain constant. Dutton et al.'s, (2001) study on gas fire emission rates found significantly high CO in homes where these unvented combustion appliances (as shown on the right) were in use, producing approximately 100ppm in two hours (would cause 10% COHb in ten hours). They suggested that a door or window should be opened when the appliance is in use, however this was unlikely if it was being used for heating, which lead to the violation of WHO standards during 2-8 hours. Furthermore, lack of maintenance could deteriorate the appliance performance, and occupants were again unlikely to get the appliance serviced.

There are carbon monoxide production limits for domestic appliances as standard, however as previously suggested, these levels and the WHO guidelines can often be exceeded at a non-negligible frequency (Wilkinson et al., 2007; Traynor et al., 2012). It is hard to draw conclusions on CO levels as there have been few studies on CO in the home. Wilson et al. (1993 cited in Croxford et al., 2008) found that 4% of 300 homes over a 48-hour period exceeded 9ppm CO, as an 8-hour average. Recent research by Croxford et al., (2008) on 56 vulnerable homes around the UK, and 270 in east London, found nearly 20% exceeded the mean 8-hour WHO guidelines. A study of 14 homes in the UK found a maximum one-hour concentration of CO of

49.8 ppm in one kitchen, equipped with a malfunctioning boiler, which suggests that air quality guidelines may be exceeded regularly in UK homes (Harrison & Holmes, 2001). In the home, the average level of CO varied between 0.3-2.4ppm in kitchens with gas cooking and 0.7-0.8ppm in kitchens without, and gas cookers also caused CO levels in bedrooms (separate from the kitchen), of between 0.4-1.8ppm (Ross, 1996 cited in Green et al., 1999). Gas cookers in use produced CO levels 2-3 times higher than background levels (Green et al., 1999). Raw et al. (2004) also found higher levels of CO in the kitchen than the bedroom in a study of 821 homes. The maximum 14-day average CO concentration did not exceed the WHO 8-hour average of 8ppm, however, exposures while cooking with gas exceed 81ppm over one hour, in excess of WHO guidelines (Raw et al., 2004). OQAI (French Indoor Air Quality Observatory) data (2006 cited in Afssat, 2007) on places of exposure to air pollutants shows that, during 30 minutes of observation, 2.6% of homes had a maximum CO concentration exceeding 52ppm and over an 8-hour period 6.4% of homes exceeded the value of 9ppm. Shrubsole et al. (2012) found that peak exposures occurred during cooking, in the kitchen. 'Cooks' (those actively cooking in the home), are exposed to twice the levels of pollutants, and over four times the levels encountered by those who never even enter the kitchen, therefore interventions for 'cooks' such as extractor fans, would be effective, and with large health benefits. However, it is important to remember that although time spent in indoor domestic environments is significant, humans frequent many other microenvironments that need consideration (Shrubsole et al., 2012).

Carbon monoxide can be readily produced in the domestic environment and levels can regularly exceed those outlined by standards and guidelines on air quality. Considering how much time the UK population spends at home, it is important to understand how this already concerning level of toxic gas is to be affected in the future by changes to our home environment; such as increases in airtightness from energy efficiency interventions.

2.3.3 The Impact of Increased Energy Efficiency on UK Housing

Recent increases in the energy efficiency of homes, driven by a requirement to reduce carbon emissions in the UK, has the potential for positive and negative effects on the health of the UK population, based on changes to indoor air quality, provisioned by increased airtightness, and reduced ventilation. This discussion must of course be seen in a much wider context, that includes topics such as fuel poverty, global carbon emission agreements, and political ambitions by various parties.

Under UK initiative to reduce pollution in the UK to 80% of 1990 levels by 2050, the UK housing stock is being made more energy efficient (Shrubsole et al., 2014). The aim of this is to reduce emission from indoors to outdoors, make homes warmer by reducing the need for fuel burning, and make heating more cost effective (Davies et al., 2004; Wilkinson et al., 2007; Brown et al., 2010; Shrubsole et al., 2014). These reductions in emissions have been based on the improvement of window glazing, introduction of cavity wall and loft insulation, and the upgrading of heating systems (Shrubsole et al., 2014; Sharpe et al., 2015). Much of the UK housing stock predates modern energy and thermal comfort standards (Wilkinson et al., 2007) and around 40% of UK homes have received upgrades from government incentives, increasing energy efficiency over the last two decades (Sharpe et al., 2015).

These incentives have had many benefits to health by increasing the winter temperature of dwellings, such as an increase in mental well-being and comfort (Clinch & Healy, 2000; Sharpe et al., 2015), a reduction in self-reported morbidity and deaths by cardiac failure, as well as increased feelings of security, and noise reduction (Wilkinson et al., 2007; Shrubsole et al., 2014; Milner et al., 2015). Furthermore, properties are becoming more watertight reducing mold, and increased airtightness is reducing outdoor sourced pollutants, which are good effects for the respiratory health of occupants (Shrubsole et al., 2014).

However, whilst the benefits of increased insulation and reduced permeability of houses has had its benefits, the increase in airtightness has many, potentially negative impacts on health, by reducing ventilation. As well as increases in insulation, airtightness, watertightness, and draft reduction, there has also been a move in the domestic environment towards timber frame houses, which reduce gas dissipation rates, and also the sealing of flues and chimneys, which all further reduce the ventilation rate of dwellings (Howieson et al., 2003; Yu & Kim, 2012).

There are four main factors that manage the concentrations of indoor air pollutant:

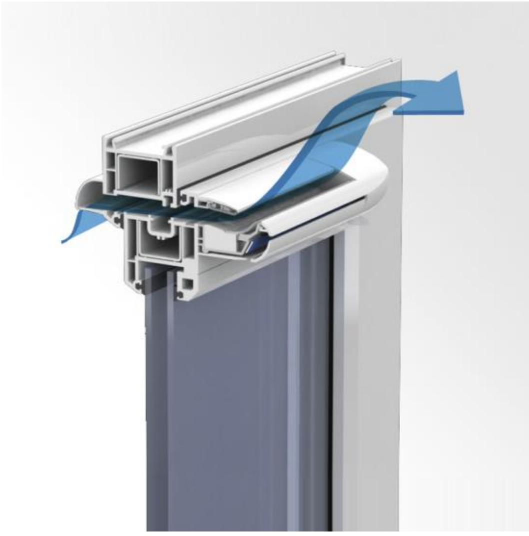
- outdoor concentrations of pollutants,
- filtering imposed by the building (diffusion, absorption etc.),
- the indoor sources of the pollutants, and
- the level of ventilation of the building (COMEAP, 2004).

Ventilation is required in dwellings for many reason including; to provide fresh air for the metabolic needs of the occupants, to provide comfort cooling in summer, and to reduce the concentrations of pollutants produced indoors (through diffusion to outdoors, and dilution from outdoor air diffusing in) (Kukadia et al., 2012). Natural ventilation is the most desirable means to control indoor air quality, such as the opening and closing of windows and the use of trickle vents, and also the extracting of pollutants locally (Yu & Kim 2012). A ventilation rate of 0.5-1 ACH (air changes per hour) is considered sufficient to prevent moisture in air, and a room's relative humidity should not exceed 70% (Yu & Kim, 2012). Ventilation can make a considerable difference to the concentrations of indoor pollutants, for example Shrubsole et al. (2012) found that occupants without extraction fans in the kitchen are exposed to a household average exposure of up to four times greater than occupants in similar apartments with functioning fans, and Milner et al. (2015) suggest that homes with higher ventilation have reduced health burdens.

There are a large number of pollutants produced in the domestic environment as well as CO, that are harmful to human health, and that are affected by increases in airtightness on homes. Pollutant release indoors is 1000 times greater than outdoor (Sharpe, 2004); levels in the home environment are often much higher than ambient levels, and exposure is often more prolonged, as most people spend longer periods indoors than outdoors (Buds et al., 2001). The Environmental Audit Committee (2010) even suggest that poor air quality reduces the life expectancy of everyone in the UK by an average of seven to eight months, and up to 50,000 people a year may die prematurely because of it. Furthermore, the Air Quality Management Resource Centre at Bristol University has suggested that the health impacts of air quality in the UK are nearly twice those of physical inactivity (approximately £10.7 billion per annum), and the costs of poor air quality are comparable to the cost of alcohol misuse, estimated to be £12–£18 billion per annum (Environmental Audit Committee, 2010).

A consensus has been reached amongst indoor air quality scientists that the reduction in ventilation and increase in airtightness in homes produced by increasing energy efficiency has had a negative effect on indoor air pollutants, causing them to accumulate to unhealthy levels (Ross & Wilde, 1999; Howieson et al., 2003; Davies et al., 2004; Sharpe, 2004; Affsat, 2007; Yu & Crump, 2010; Kukadia et al., 2012; Shrubsole et al., 2012; Yu & Kim, 2012; Howieson et al., 2013; Milner et al., 2015; Sharpe et al., 2015). While reducing ventilation can help protect against the entrance of harmful pollutants from the outdoor air, results demonstrate that reducing the permeability of dwellings without providing additional ventilation, leads to significant increases in indoor derived pollutants (Hamilton et al., 2015). Some homes, tested for airtightness, have been found to be tighter than the design value, resulting in further uncertainty about the adequacy of ventilation; increasing airtightness needs to be considered as a part of the ventilation design, to ensure that there is no reduction in the indoor air quality (Kukadia et al., 2012).

Sundell et al. (2011 cited in Kukadia et al., 2012), concluded that inflammation, respiratory infections, asthma symptoms and short-term sick leave increase with lower ventilation rates. Other health effects may only become apparent after years of exposure or after long or repeated occurrence (Sharpe, 2004). Asthma prevalence in Britain has risen by six-fold in the last 30 years (Howieson et al., 2013) and 20% of population suffers from asthma, or allergies from indoor substances (Sharpe, 2004). Low ventilation and increase in watertightness can cause increases in heat and humidity, which are prime conditions for house dust mites (HDM) to thrive; HDM allergens are a common cause for asthma (Howieson et al., 2003; Howieson et al., 2013; Shrubsole et al., 2014). It is evident therefore, that the increase in airtightness from energy efficiency measures, has had a broad and significant impact, on the indoor air quality of dwellings.



Ventilation can be added to homes during these upgrades to combat the increased airtightness introduced from insulation. Trickle vents (shown on the right) can reduce the airtightness caused by using double-glazing (Shrubsole et al., 2014) but, they can be easily sealed by occupants, thereby making their positive impact, redundant (Kukadia et al., 2012). Howieson et al. (2013) found in their study that CO_2 concentrations measured in occupied bedrooms were at unacceptable concentrations. Such high levels confirm that airtight dwellings with only trickle ventilators as the 'planned' ventilation strategy do not meet the standards demanded by building regulations. Furthermore it is possible that increases in CO_2 could exacerbate the effects of CO poisoning. Heat recovery and mechanical ventilation can effectively improve indoor air quality and provide effective energy savings. For example, Kim et al. (in Yu & Kim, 2012) found that formaldehyde levels were reduced by 54.6% after heat recovery ventilators were operated for 24 hours, and 82% in 168 hours and energy usage was reduced by 20.26%. However, mechanical ventilation and heat recovery systems, may not always improve air quality due to potentially ineffective use, lack of understanding, and poor maintenance by occupants (Shrubsole et al., 2014; Hamillton et al., 2015).

There are a number of tradeoffs in the move towards more energy efficient homes. Firstly, minimizing heat loss, greenhouse emissions and reducing health impacts from cold, and reducing pollutants from indoors and outdoors. The ideal ventilation rate is therefore a compromise between the need to reduce heat loss through ventilation, maintain thermal comfort, reduce ingress of outdoor pollutants, and ensure the removal of indoor pollutants (Das et al., 2012). If this compromise is not achieved, there could be an overall negative impact on health as those issues associated with indoor pollutant levels could be more detrimental to health than those associated with low indoor temperatures (Hamilton et al., 2015; Milner et al., 2015). Therefore, it is important to provide the correct balance between airtight buildings to conserve energy and reduce CO_2 emissions, whilst simultaneously providing effective ventilation for occupants, and maintaining a healthy indoor air quality. To ensure that this balance is reached, it is important to understand the impact that increased energy standards, and airtightness levels, may have on ventilation requirements and indoor air quality (Kukadia et al., 2012).

Strategies for improving indoor air quality should be based on sound science. We need a better understanding of indoor sources of an occupant's exposures, how they affect health and productivity, and how they can be minimized (Sharpe, 2004). We need to understand the impact of energy efficient refurbishments on the future of exposure, and how these effects can be reduced (Shrubsole et al., 2012; Milner et al., 2015). Consideration of ventilation, thermal comfort, and the prevention of health risks, improves satisfaction and productivity. Indoor air scientists have long argued that the control of emissions from consumer products in buildings should be an important part of policy and action, to protect the public from adverse health from indoor air (Yu & Crump, 2010). We need to consider the linkages that exist between buildings, humans, well-being, and environmental impacts, when forming policies (Shrubsole et al., 2014).

2.3.4 Impact of Airtightness on CO Levels in the Home

The impacts on indoor pollutants of increased energy efficiency of homes has been discussed, and the health effects that these can have on the occupants of energy efficient homes, however, carbon monoxide is not regularly evaluated in this capacity. CO is one of the more significant toxins, as the effect of it is known to be death, whilst the mortality impact or other pollutants are only implied.

When the impact of carbon monoxide poisoning in the domestic environment is discussed, the issue of increased energy efficiency and airtightness of homes through the improvement of glazing, and increase in insulation in lofts and cavity walls, is raised. However, there is very little research on the increase of pollutants from indoors after these measures are undertaken, and even less when indoor CO specifically, is considered. Hall and Pocock (2015) did test the effect of ventilation on CO levels from gas appliances. They found that CO levels were greater in reduced ventilation and these safe gas appliances did not release CO at equilibrium high enough to cause CO alarm activation and immediate harm. However the levels reached for example in a cooking experiment, where all four gas hobs and the oven were at maximum output, produced levels of 29.5 to 15.2ppm with increased ventilation, which would be harmful if exposed to regularly, which would be expected in cooking. More research like this is needed to understand these prolonged effects, how long the levels are maintained in the home under reduced ventilation, and how ventilation affects CO production from other, non-gas appliances.

Despite this lack of knowledge and scientific backing, this argument continues to be used as a tactic to improve awareness on CO, and the uptake of carbon monoxide alarms. Furthermore, the introduction of more effective and energy efficient heating methods in homes as an additional measure could have a beneficial effect by reducing CO levels, by reducing old, problematic boilers. The true impact on carbon monoxide levels, whether beneficial or not, is unknown, and therefore should not be utilised as an argument for CO policy until there is sound, scientific data present. It would be prudent to undertake research to measure the true impact on indoor CO levels of all these measures individually, and collectively, when utilised to increase energy efficiency.

There is currently a small amount of research on the effect of increased energy efficiency in homes on other pollutants emitted indoors, and their health effects, including but not limited to; mould, dust mites, radon, volatile organic compounds (VOC) and heat. It is a general consensus that increased airtightness, increases the concentrations of these pollutants in the home, and thus it would not be unreasonable to assume the same for carbon monoxide, considering the decrease in ventilation available to dissipate levels (Tam et al., 2012). However, questions arise on how reflective this information on the 'pathways of CO level increase' truly is, and, whether this information on the health effects of other pollutants is really transferable to carbon monoxide poisoning. The answer to these questions are not known, and only research into the effect of increased energy efficiency on CO levels in the home, can rectify this important gap in in our knowledge.

Carbon monoxide is a dangerous poison; it is harmful to humans at high and low concentrations, readily produced in the domestic environment, and impossible to detect without a CO alarm. Not only do we know little of its effects on humans, but also we know little of how this will change with increased airtightness in the home. Chronic, low-level carbon monoxide poisoning makes a considerable, potential impact on the UK population, due to its predicted frequency, non-specific symptomology, and long-term health effects (Green et al., 1999; Tam et al., 2012). Based on the effects of airtightness on other pollutants, leading to long-term low-level exposures of occupants, it is highly likely that chronic CO poisoning will make an even larger impact on the UK population, than it does currently. However, these effects should be established through scientific research. Furthermore, the effects of increasing energy efficiency in the home on acute high-level CO poisoning has not been raised. Although acute carbon monoxide poisoning is a rarer occurrence, and affects less of the population, how high-level emissions are affected and retained in dwellings without adequate ventilation, should still be investigated.

Carbon monoxide is a prolific poison that should be monitored in our environments (Raub et al., 2000). Therefore as we change our environments, the impact of this poison is expected to change, and this should also be surveyed. Considerably more research is required to understand the impact of carbon monoxide poisoning, both acute and chronic, with the increase in airtightness of our homes, in order to better mitigate and protect the public.

2.3.5 Conclusion

The issue of indoor air quality and ventilation in homes has reached a higher level of importance in recent years. This is due to the move towards increased energy efficiency of UK homes by increasing airtightness and watertightness, and reducing ventilation and permeability. This reduction on ventilation is causing a build-up of harmful pollutants in the home environment, causing increased health issues, and potentially outweighing the health benefits of increasing winter warmth through home insulation.

This issue is significant when we consider the amount of time the population of the UK spends indoors (approximately 90%, with 70% of our time in the home environment) (Brown et al., 2010; Yu & Crump, 2010; Das et al., 2012) and the considerable danger posed by carbon monoxide production in the home. Carbon monoxide is an undetectable poison that is harmful to humans at both low and high concentrations; it is readily produced in dwellings due to the spectrum of fuel-burning appliances present. Chronic low-level carbon monoxide poisoning has a significant impact on population health as it is potentially frequent, undiagnosed, and with long-lasting health effects. A future of increased airtightness in dwellings is set to exacerbate this already harmful and misunderstood situation of carbon monoxide poisonings.

More research is needed to determine the effects of reduced ventilation in energy efficient housing on all pollutants, and the health effects they pose on occupants. Considerably more research and funding should be applied to ambient levels of carbon monoxide in the home and its health effects. Furthermore, the effects of increased airtightness in energy efficient homes on ambient carbon monoxide levels specifically needs to be investigated, and the effects of acute high-level CO production. Too little is known about the health effects of carbon monoxide at all concentrations and even less on how this is will be affected by reduced ventilation in our future homes. What is known however, based on limited case studies of pollutants, and the significant effects of CO at all concentrations, is that there *is* a problem.

2.3.6 Recommendations

- More research should be conducted into the effects of increased airtightness on the plethora of toxins present in the domestic environment and their impact on the health of occupants.
- Studies should be implemented to research the impact of increased airtightness in homes, on the levels of carbon monoxide for both chronic low-level concentrations and high-level acute CO leaks.
- The preceding should be linked to the health impacts on the occupants for corresponding concentrations.

- Further research should be provisioned to find methods to reduce the burden of indoor pollutants on occupants such as recommendations on activities and ventilation to reduce emissions and concentrations of pollutants.
- The work of indoor air scientists should feed more regularly into policy in order to protect the public from pollutants produced indoors.

3 Data Collection

Data collection and subsequent analysis is an essential part of understanding carbon monoxide poisoning and prevention. The following part of the co+Impact study outlines some of the current issues in data collection affecting statistics on CO cases and the figures on individuals exposed to CO.

ICD codes (International Statistical Classification of Diseases and Related Health Problems; as discussed below) are useful for collecting and comparing mortality data within and between countries. Carbon monoxide poisoning currently has a single code to represent a death caused by CO. However there is overlap between this code and the multiple codes for deaths caused by fires, and therefore fire related CO deaths could be wrongly excluded from research that only considers the CO ICD code and excludes fire ICD codes. This, coupled with the lack of detailed information provided by ICD, skews our perception of the figures of CO deaths in the UK.

An additional way to improve figures on carbon monoxide incidents, to better understand the impact on the UK population, would be the pooling and analysis of multiple data sets. This would allow for more thorough and complete statistics on CO incidents, that have the capacity for use as a carbon monoxide public health surveillance process. This would aid understanding, treatment, prevention, and devise a possible foundation for the creation of better CO policies, for the protection of the UK public.

This next sections emphasise these issues in data collection and analysis that are affecting statistics on CO poisoning incidents and therefore our understanding of the impact of CO on the UK. Recommendations are made for future actions and processes that could be initiated to improve our understanding of carbon monoxide poisoning for the purpose of prevention in the UK.

3.1 Accidental Non-Fire Related Carbon Monoxide Poisoning and ICD Codes

3.1.1 Introduction

One of the most common causes of CO poisoning is exposure to fires, closely followed by motor vehicle fumes and faulty heating or cooking appliances (Ball et al, 2005; Cobb & Etzel, 1991; Homer et al, 2005; Popovic et al, 2009; Ruas et al, 2014). Any of these sources, combined with a lack of ventilation, can let CO levels rise to harmful levels.

Death from smoke, fire and flames accounts for 18.8% of deaths from accidental carbon monoxide poisoning (Braubach et al., 2013) and 50-80% of fire related deaths are the result of smoke inhalation as opposed to burns, as estimated by Holstege and Kirk (2006 cited in Braubach et al., 2013). In a fire-related carbon monoxide incident, it can be difficult to attribute death to CO poisoning (Ruas et al, 2014) when other factors such as heat shock, asphyxiation, burns, smoke inhalation and a cause of death prior to the fire are considered. Carboxyhaemoglobin (COHb) levels are an important factor in determining the cause of death of a victim of fire; high levels (usually diagnosed at 50% COHb (Anderson et al, 1981b)) suggest that the victim would have been alive at the time of the fire and low levels would indicate a death prior to the fire (Chaturvedi et al, 2001). Anderson et al (1981b) found that 52% of their study sample on fire deaths, died from carbon monoxide poisoning and another possible 33% from levels below common diagnosis.

The *International Statistical Classification of Diseases and Related Health Problems* (ICD) is an international classification standard produced by the World Health Organisation (WHO). The system is used worldwide to track morbidity and mortality statistics and make international comparisons on diagnostics and data collection possible. The system is revised every few years and the most current system, which is in use in many countries, and in the UK is ICD-10. Carbon monoxide poisoning has one single code under this system without the use of additional sub-codes for the cause, i.e. whether the CO came from a faulty boiler, a blocked flue, a BBQ grill, generator, etc. Fire related incidents have a separate code with various sub-codes depending of the type of incident. However, overlap exists between the two incidents with CO poisoning occurring regularly in fires.

It is important to stress that the term 'fire' or 'fire-related' in this context should not be taken to be to *a house that is on fire*. The 'fire' code X02, for example, can be used to classify the illness or death of a person caused by a fireplace (which can be CO or another issue related to the fireplace). Not a house-fire caused by a fireplace but, for example, siimply a buildup of CO from a partially blocked chimney.

T58: Toxic Effect of Carbon Monoxide **Incl.** from all sources

X00-X09: Exposure to Smoke, Fire and Flames
Incl. fire caused by lightening
Excl. fire caused by arson, secondary fire via explosion and transport accidents
• **X00:** Exposure to uncontrolled fire in building or structure
  – Incl. collapse of/ fall from/ hit by/ jump from building or structure, and fire/ melting/ smoldering of furniture and fittings
• **X01: Exposure to uncontrolled fire not in a building or structure**
  – Incl. forest fire
• **X02: Exposure to controlled fire in building or structure**
  – Incl. fire in fireplace/ stove
• **X03: Exposure to controlled fire not in building or structure**
  – Incl. campfire
• **X04: Exposure to ignition of highly flammable material**
  – Incl. ignition of gasoline/ kerosene/ petrol
• **X05: Exposure to ignition or melting of nightwear**
• **X06: Exposure to ignition or melting of other clothing and apparel**
  – Incl. ignition/ melting of plastic jewelry
• **X08: Exposure to other specified smoke, fire and flames**
• **X09: Exposure to unspecified smoke, fire and flames**
  – Incl. burning/ incineration/ smoke inhalation

De Juniac et al (2012) suggest that there are already limitations in our current data sets on CO incidents and the true burden of unintentional CO poisoning on the population is unknown. Ball et al (2005), Ralston and Hampson (2000) drawing from Cobb and Etzel (1991), and Harduar-Morano and Watkins (2011) suggested that accidental CO deaths are preventable but for prevention programs to be effective, both the population affected and the practices that put them at risk must be identified. The inability to accurately define these deaths and include them in research alters our understanding of the true impact of CO on the population and the numbers of those affected.

The following discussion deals with two separate but related issues:

- **Preventable vs non-preventable incidents** – while technically most incidents are ‘preventable’, in this context, a CO poisoning from a faulty boiler is considered ‘preventable’ by means of annual boiler checks and proper use, while being poisoned by CO because one is in the middle of a burning building, is considered preventable by fire prevention, and therefore not preventable by the same recommendations.

- **Fire related vs non-fire related CO incidents** – fire related CO incidents and codes are diverse and include more than just house fires; they include fireplaces and the use of BBQs for example. However, fire codes are often excluded from research that limits its data to 'non-fire related' cases, under the assumption that fire codes are limited to just 'conventional' building fires, without sampling specific sub-codes.

Fire cases are very often excluded in CO poisoning studies that choose to focus on non-fire related CO poisonings (Clower et al, 2012; Dianat & Nazari et al, 2011; Fisher et al, 2014; Henn, 2013; Nazari et al 2010), as they are often deemed 'preventable' by alternate awareness campaign methods, among other reasons. However, the way that fire related CO deaths are defined in these studies varies greatly and in many cases, fire-related deaths *can* be defined as 'preventable' by the same means as CO, and therefore their absence from such studies is unjustified.

3.1.2 ICD-9 to ICD-10 and on to ICD-11

The ICD system was first established in 1893 and is reviewed regularly, with its first revision in 1900. Carbon monoxide poisoning is currently included under the code T58. Changes thorough time however, have varied in the level of importance that they place on the causes of CO gas, affecting the available codes, and the information that can be gleaned from them in statistical analysis.

The change from ICD-9 to ICD-10 in 1994 saw a reduction in codes for carbon monoxide poisoning; from sub-codes for the cause of CO gas in ICD-9, to one code for CO gas exposure in ICD-10. Fire deaths, which include smoke, fires and flame deaths however, were expanded to include other areas of ignition commonly seen. This move has not been of benefit to CO research. Although studies (Bowes, 1979) have concluded that the codes have not lead to a bias in the way that deaths have been recoded year to year there is less information available about the cases to build a clear picture of the circumstances of current CO deaths (Fisher et al, 2014). Similarly, the prior move from ICD-8 to ICD-9 in 1979 saw a change in the way fire deaths were coded for children with more sub-codes being created for smoke and vapours than CO poisoning, but did not lead to inconsistencies (Fisher et al (2014)).

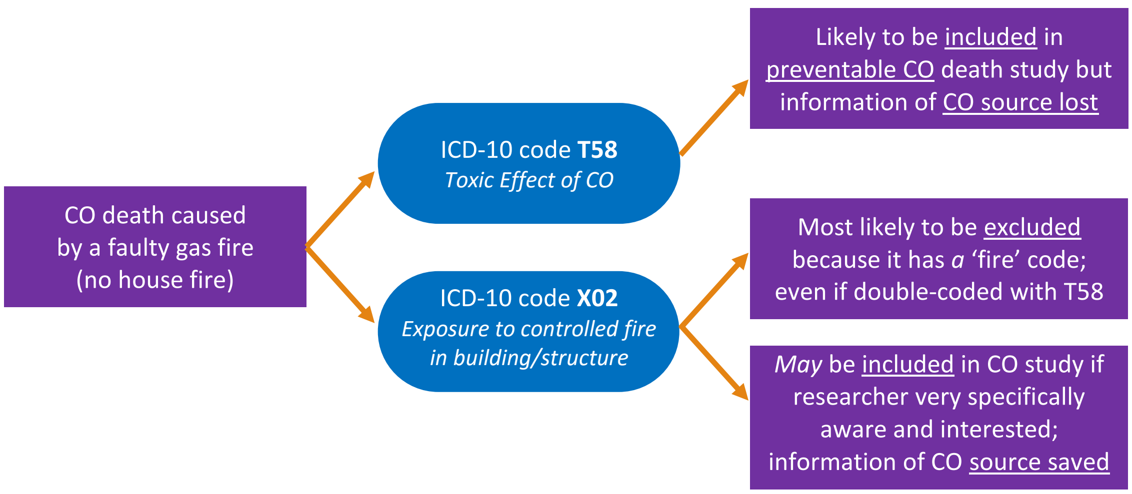
Braubach et al. (2013) suggest that if the ICD-10 system and T58 code is to be used for the surveillance and monitoring of carbon monoxide incidents then it should be improved. This study feels that the codes for CO deaths should be re-examined and expanded in ICD-11 (expected 2018) to provide more information about the type of death.

Chronological changes in the way carbon monoxide poisoning has been coded in ICD have varied the level of information that can be gleaned in statistical analysis. To reiterate, the codes for CO incidents should be re-examined and expanded in ICD-11 to provide more information about the type of death, seeing as there is a clear difference in research interest and the behaviour of the victim in incidents, and the potential of the codes to be used for the surveillance and monitoring of carbon monoxide incidents.

3.1.3 ICD Coding in Fire-Related CO Poisoning

The combination of CO and fire ICD codes in incidents is a topic for debate, and has the potential for high variability in the application of codes to incidents, based on subjectivity. Whilst many feel that the fire incidents are separate from CO cases, in the cases of both fires and CO poisonings, there is overlap between the two.

One of the more significant aspects to consider when discussing ICD coding is that the code assigned is determined not by the CO researcher but by the medical professional at the time of death or emergency department visit. Therefore, it is entirely down to the medical staff to code the incidents accurately and consistently. The variations in the definitions of fire-related carbon monoxide deaths begin here and this could have a positive or a negative effect on CO incident data. If coroners do not consider 'fire' to be present in a CO death, then it will be coded as a CO death without source information, despite the available and accurate fire-related codes. However, if they are in fact coded as fire-related CO deaths, then more detail is available and the code has been accurately applied. But variation would exist here and as previously discussed, some individuals would be missing from the sample, this would then reduce the numbers of CO deaths included in ICD data research studies. Therefore whether CO fire-related deaths are defined in the same way by researchers and medical staff and whether the ICD code system is applied correctly at the outset can alter the accuracy of the ICD code data.



In the case of ICD code use for fire-related CO incidents, the code is for the cause of death of the victim, not for the cause of the CO production (Ghosh et al, 2015; Girman et al, 1998); therefore many CO deaths will never be coded as fire-related as the fire would be the cause of CO gas but not the cause of death.

Girman et al (1998) for example chose to exclude fire and vehicle related CO poisoning on the basis that CO poisoning must be the clear primary cause of death whereas in these instances, the fire or vehicle accident may be the cause of the death, and CO poisoning a consequence of the event. However, it is evident from studies (Ghosh et al, 2015) that some deaths *are* coded with these two ICD-10 codes, both CO and fire-related. We should then ask the question, why is it that in some instances the cause of CO is important, and in some it is not? Are all fire-related CO poisonings coded this way or is the fire aspect sometimes excluded?

Without knowing the division of deaths by fire sub-codes it is difficult to determine whether accidental building fires for example are more often twin coded with CO poisoning, or the controlled indoor fire or another code all together. But it is clear that at times this information appears to be important to convey, and at others, unimportant. Again, there is a case of inconsistency in ICD code utilisation in research, as some researchers suggest that the twin codes for CO and fire should not be used but yet they exist and are used to formulate samples for research.

The combination of CO and fire ICD codes in incidents is subjective but some deaths are coded with these two ICD-10 codes. There is overlap between the two but to what extent; e.g. are the building fires more often coded with CO poisonings, or the indoor fire.

3.1.4 The Definition of Fire-Related CO Death

The issues with the exclusion of fire-related carbon monoxide incidents are not only in the definition of ICD codes, but also in the definition of fire-related CO incidents in studies and the chosen study sample. This leads to the exclusion of valid CO incidents from research.

On first thought, a fire-related incident would appear to be building fires (Cobb & Etzel, 1991) however the ICD-10 sub-codes cover much more than this including, but not limited to:

- uncontrolled building fires;
- controlled building fires such as stoves and fireplaces;
- ignition of nightwear; and
- ignition of fuels.

When ICD code data is utilised in studies of deaths by CO, all fire codes are excluded without thought.

In studies where media data is ‘clipped’, each case is collected and critiqued individually from media, not ICD data, as in de Juniac et al’s (2012) and Fisher et al’s (2013) studies. In these studies fire-related deaths were understandably excluded on the basis of preventability (discussed later), though fireplace and cooking/heating related incidents were specifically and usefully included (unlike other research discussed above). However, if a media clipping or journal article study wanted to exclude building fire related CO cases for example, and excluded ‘fire’ from their search terms, they may inadvertently exclude fire-places etc. from their data. Dianat and Nazari (2011) on the other hand used hospital data in their study and excluded fire-related deaths without definition and also those from charcoal grills. The Office of National Statistics collects coroners and doctors data on CO incidents; but, they do not directly stipulate that they include fires and suicides, but exclude house fires (de Juniac et al, 2012). Cobb and Etzel (1991) chose to exclude all ICD-9 codes in their study relating to fire, however retained all vehicular codes (another area for awareness campaigns).

Ghosh et al (2015) commented on the different estimates of individuals that die from CO poisoning annually, produced by different studies and found that they did not correspond with their own findings. They considered a number of variables as the cause of these differences that no doubt will continue to make a change to fatality figures in research, despite the issues in classification suggested here. Although there are many distinct variables and errors in these studies, the difference between the classification of ‘preventable’ (by CO awareness campaign) and ‘fire-related’ CO poisoning is an unnecessary one that can be changed.

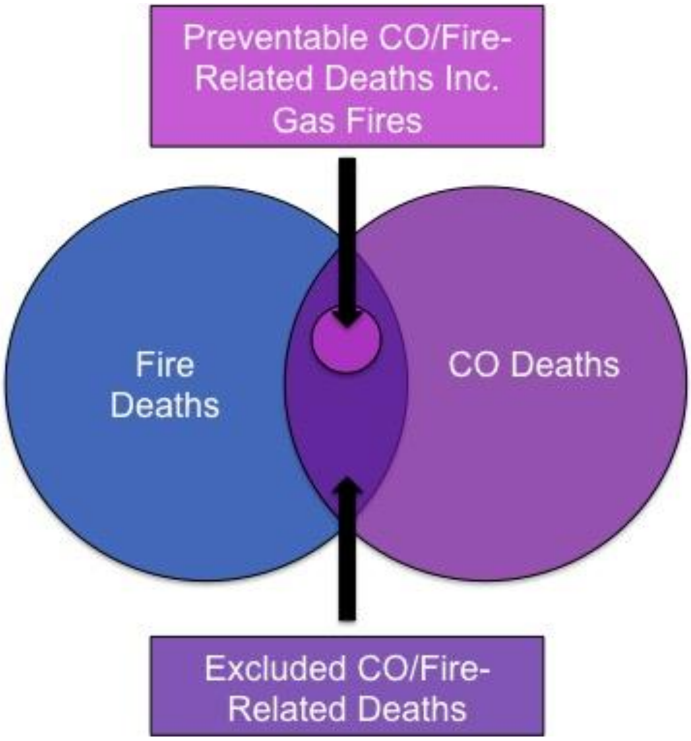
The DIDR report (Downstream Incident Data Report) produced by the Gas Safety Trust and Downstream Gas should represent a subset of the preventable population affected by CO, determined by gas appliance use. However, they include gas fires as a source of CO from gas whereas in other studies they would be excluded. With various studies choosing to tabulate different incidents (irrespective of their ability to achieve a complete sample) the true figure of the number of preventable deaths by CO poisoning is inevitably inaccurate. This information is then often extrapolated to suggest the figures for those who unknowingly died of CO poisoning, and those suffering from CO poisoning without diagnosis. Although these figures will still be estimated, they can be made more reliable; but it should be not be forgotten that they are estimates based on other estimates, due to the lack of agreed research protocols for CO incident studies.

The variations in the definition of fire-related carbon monoxide incidents by researchers, causes unjustified exclusion of CO cases from research studies, and differences and overlap between the samples used in these research projects. This leads to a lack of understanding of the true numbers of individuals affected by carbon monoxide poisoning in the UK.

3.1.5 ‘Preventable’ CO Poisonings

One of the reasons for excluding fire-related carbon monoxide incidents from research is the assumption that fire/CO incidents are not preventable by the same means as other carbon monoxide incidents. For example, a house fire is not prevented by the same recommendations as those suggested by CO campaign methods to prevent CO release from boilers. However, there are fire-related CO incidents that *are* preventable by the same recommendations.

The premise of researching death due to preventable carbon monoxide poisoning is justifiably sound and important to understanding the true numbers of individuals affected by CO poisoning, despite the work of CO awareness campaigns. It is often considered that fire-related CO deaths fall alongside intentional CO deaths and are not preventable by the same means as other unintentional exposures (Clower et al, 2012; Wilson et al., 1998; Cobb & Etzel, 1991) that can be prevented through the proper installation, use and maintenance of fuel burning devices and the use of CO alarms (Ghosh et al, 2015; Harduar-Morano and Watkins, 2011). However, many such studies fail to ascertain that this is the reason for excluding fire-related CO deaths in their research. In the case of the use of ICD code data in particular, fire-related CO deaths are coded by a variety of specific circumstances, many of which can be related to CO poisoning and some of which *are* actually preventable by the same campaign methods as other CO poisonings.



In an alternative study to normal convention in the USA, Homer et al (2005) investigated both the fire-related and intentional CO fatalities and considered these two incidents similar and not preventable. Similarly, Ruas et al (2014) used coroners' reports from Portugal to examine the physical signs of CO on fatal victims without excluding any aetiologies. Studies that exclude fire-related CO deaths by blanketing them as 'non-preventable', exclude all fire-related CO deaths rather than picking more specific codes that *can* be deemed preventable fatalities. An example of this could be CO poisoning from a controlled indoor fire (ICD-10 X02), which includes a fireplace or stove and therefore could include a gas fire, or hob, or the controlled outdoor code (ICD-10 X03), which could include a barbeque. The prevention of CO poisoning from gas fires and barbeques are critical segments of CO safety campaigns and entirely preventable by the same standards and recommendations for use of appliances that *are* included in non-fire related CO research.

Figures from ICD code data, provided by the Cross Government Group on Gas Safety and CO Awareness (CGG, 2015) suggest that the number of deaths by carbon monoxide poisoning from smoke, fire and flames in England and Wales through 2005-14 were 397 in total. However, they do not provide broken down figures for each of these fire codes, so the portion of these attributed to 'over-lapping' areas as suggested above cannot be determined. However, in Northern Ireland, the number of deaths from carbon monoxide poisoning from a controlled, indoor fire for example, from 2009-14, was two (CGG, 2015). These two figures illustrate that including and excluding various categories can lead to drastically different dimensions and provides an insight to the figures missed in these 'non-fire related' CO studies.

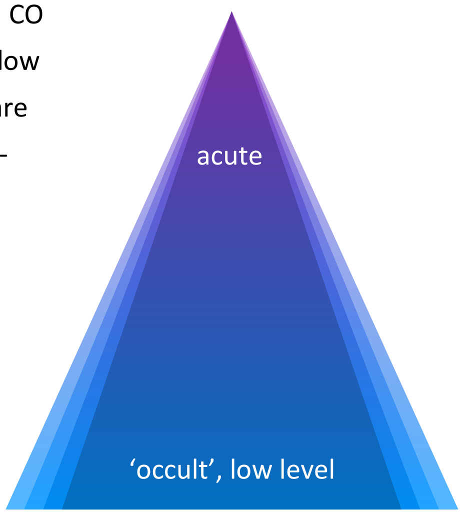
Additionally, the change in legislation for private landlords in England & Wales regarding the installation of carbon monoxide CO alarms requires them to be present in rooms with a solid fuel-burning appliance such as a fireplace or wood burner etc. (The Smoke and Carbon Monoxide Alarm (England) Regulation 2015). Although this new policy is quite limited, it has the potential to save lives in these cases. However, CO research utilising ICD code data does not include these individuals that the policy is currently trying to protect as they are often excluded under the heading 'fire-related' CO deaths. In short, those being protected from CO are often unaccounted for in ICD sample research where fire-related CO deaths are excluded. Unless this changes, differences will be seen in later years in the numbers of fire-related CO deaths (due to the change in the law) but with no explanation from ICD statistical analysis therefore no change will be observed in statistics on CO non-fire related deaths making the change in the law 'unjustifiable', i.e. no benefit will be demonstrated from ICD.

By excluding these ICD-10 codes from CO research, not only is a portion of CO deaths missed in the research and remains unaccounted for, but persistent CO safety campaigns appear to be unjustified. There is little point for CO safety campaigners in telling the public to get their gas fires serviced or chimneys swept if studies on ICD data do not include these incidents as they are considered fire-related CO cases, so the impact of these messages will remain unknown. Studies should attempt to choose appropriately and justifiably which cases are excluded, and refrain from using blanket terms such as 'fire' and 'non-fire' related in exchange for more accurate terms, such as 'building-fire'.

In conclusion, fire-related carbon monoxide incidents are often excluded from CO research on the assumption that they are not preventable by the same means as other carbon monoxide incidents. However, there are fire-related CO incidents that *are* preventable by the same recommendations and much more overlap between codes than previously thought. This means that some of the messages and recommendations of CO awareness campaigns, and the change in legislation, do not have corresponding data analysis for their impact.

3.1.6 The Pyramid of Disease

Another frequent reason for excluding fire-related CO poisoning incidents is when a study concentrates on low level, chronic CO poisoning. Fire-related CO incidents are more commonly associated with death rather than long-term poisoning (Ghosh et al 2015) and it is thought that their inclusion would therefore distort the assumptions of the pyramid of disease.



Wright (2002) suggests that CO poisoning can be viewed as a *pyramid of disease* where acute poisoning is the ‘tip of the iceberg’ and low level undiagnosed poisoning or ‘occult’ poisoning is the base. What epidemiological and population studies are trying to determine is the size of the base, i.e. how many people are affected by low-level, chronic carbon monoxide poisoning.

However, as previously discussed, there are codes such as ICD-10 X02, for exposure to an controlled indoor fire, that are preventable by the same means as other CO exposures and furthermore could easily, as in many cases, cause chronic low level poisoning as well as death. The case of Lynn Griffiths’ family was caused by the blocked flue of the gas fireplace and lead to long-term chronic exposure leading to the death of her husband and long term suffering for her and her children. This demonstrates that some fire-related CO incidents can contribute to data on chronic low-level CO poisoning, but are unreasonably excluded. These kinds of cases of chronic suffering and even deaths due entirely to CO are unlikely to be included as such, leading to unreliable and invalid data in research.

The prevention of further incidents such as these from gas fires is a key factor in carbon monoxide poisoning campaigns. The exclusion of these individuals from figures on acute deaths and chronic illness from CO is counterintuitive for research purposes and does not reflect the aims of carbon monoxide awareness campaigns. Furthermore, the true number of incidents of chronic low-level carbon monoxide poisoning is unknown, and excluding cases on the basis of the presence of a fire element would distort data on chronic CO further.

3.1.7 Conclusion

There are already limitations in our current data sets on CO incidents and the true burden of unintentional CO poisoning on the population is unknown. Accidental CO deaths are preventable but for prevention programs to be effective, the population affected and the practices that put them at risk must be identified. The inability to accurately define these deaths and include them in research alters our understanding of the true impact of CO on the population and the numbers of those affected. There appear to be at least two different categories of excluded CO deaths: those that are undiagnosed, and those that are known to have a CO component but are intentionally excluded from studies.

The International Classification of Diseases system (ICD) is used worldwide to track morbidity and mortality statistics and make international comparisons on diagnostics and data collection. Carbon monoxide poisoning has one code under this system without any additional sub-codes for the cause of gas production. Fire related incidents have separate codes. However, overlap exists between the two incidents with CO poisoning occurring regularly in fires. CO deaths are therefore likely to be recorded as fire-deaths and can disappear from both statistics and CO research.

Research in ICD code data should be conducted, specifically which fire codes are most often coupled with CO code data and how ‘anecdotal’ or ‘media’ evidence would be coded by different individuals. Additionally, ICD-11 should attempt to include more CO codes like ICD-9 already had and that ICD-10 is now lacking, or should allow for more combination codes where the combustion link between fire and CO can be utilised such that the fire codes can be used to give further detail to a CO death.

Fire cases are very often excluded in CO poisoning studies that choose to focus on non-fire related CO poisonings (Clower et al, 2012; Dianat & Nazari et al, 2011; Fisher et al, 2014; Henn, 2013; Nazari et al 2010), as they are often deemed ‘preventable by alternate means’. However, the way that fire related CO deaths are defined in these studies varies greatly, and often fire-related deaths can be unjustifiably excluded. Studies that claim to be researching the number of deaths by preventable CO poisoning should attempt to accurately define their sample and in the case of utilising ICD code data, investigate which codes should be included in order to validate the sample. Non-fire related CO deaths should not be used as a blanket term for preventable CO deaths as it is misleading and excludes preventable cases that attempt to be covered by campaigns. Alternatively, if preventable deaths are to be studied it should be stated as such with ‘preventable CO deaths’ defined in the study.

3.1.8 Recommendations

- Studies that claim to be researching the number of deaths by preventable CO poisoning should attempt to accurately define their sample;
- Non-fire related CO deaths should not be used as a blanket term for preventable CO deaths as it is misleading and excludes preventable cases;

- Research in ICD code data utilisation should be conducted; specifically which fire codes are most often coupled with CO code data, and how 'anecdotal' or 'media' evidence would be coded by different individuals, and
- ICD-11 should attempt to include more CO codes like ICD-9, as ICD-10 is lacking, or should allow for more combination codes.

3.2 One Data Set

3.2.1 Introduction

Carbon monoxide poisoning can be considered a pyramid of disease, where deaths from CO poisoning represent the smaller 'top' of the triangle, the larger middle portion consists of poisonings requiring medical attention and the base is made up of many more low-level poisonings affecting daily morbidity. This pyramid can be viewed in the case of carbon monoxide as more of an iceberg, where just the tip (the deaths and a few survivors) are observed and the rest is hidden below the surface of the water where its size is undetermined and the number of individuals affected by CO, is unknown. (Wright, 2002).

There are many reasons why we do not know the true numbers of individuals affected by carbon monoxide. One reason is that the symptoms of CO poisoning are nonspecific, leading to much misdiagnosis by victims and medical professionals. Another is that the UK has no one-data-set for collating CO incidents; rather there are many data sets, collected by many organisations all with different inclusion criteria. In order to understand better the impact of carbon monoxide poisoning on the UK population, data sets should be collated by one institute, and reviewed.

3.2.2 Quantitative Data Sets

The UK utilises several different data sets on carbon monoxide incidents that have differing criteria for inclusion. These include the Office of National Statistics (ONS), Hospital Episode Statistics and data from the Health and Safety Executive (HSE) (Basarab et al., 2008). In addition there are also media reports, data from the Gas Safe Register, Gas Distribution Networks, emergency calls data, the Department of Health, other fuel organisations (including oil, solid fuel, LPG (liquid petroleum gas)), Emergency Services, and coroners. An example of differing criteria would be the data of incidents based by specific fuels (such as LPG or oil) from fuel companies, as opposed to data on deaths by carbon monoxide poisoning from the ONS, or even any incidents caused by gas as identified by the HSE. This inhibits our understanding of the number of carbon monoxide poisoning incidents in the UK and the details of such events.

Regularly merging these data sets on CO incidents and reviewing such information would allow better understanding of the potential numbers of individuals affected by carbon monoxide poisoning. Furthermore, additional data sets should be identified, expanding the potential for this method. This could include additional fuel industries or media reports (which would require processing prior to analysis). Basarab et al. (2008) analysed some of these main data sets (ONS, HSE, and Hospital Episode) for their potential for a UK carbon monoxide surveillance system. A public health surveillance system collects data on events, exposures, and outcomes, for analysis and interpretation, for the purposes of prevention and control. For CO, this is already successfully underway in France, and in the UK would identify populations at risk, enable rapid response to emerging threats, establish relationships between hazards and cases, optimise interventions and prevention strategies, and inform public health policy-making (Basarab et al., 2008). They concluded that a combination of these and other existing data sets would be a potentially, highly effective foundation for CO surveillance.

It would be highly beneficial to be able to combine these data sets to better understand the quantitative impact of carbon monoxide poisoning on the UK population. Furthermore, considering the differences in criteria between the groups it would be wise to ensure where significant overlap, or alternately, gaps in the statistics occur.

3.2.3 Qualitative Data

Qualitative data can be very valuable for carbon monoxide research and a good addition to the many quantitative data sets already in use. ‘Media Clipping’, a review of press publications, and the collection of qualitative data from victim accounts are useful examples. Experience in the US suggests that victim groups are well placed to do this data collection.

In the wake of natural disasters in the US, incidences of carbon monoxide poisoning increase mostly due to the use of generators during power outages. The Centre of Disease Control and Prevention (CDC) and FEMA (Federal Emergency Management Agency) collect incident data on carbon monoxide for surveillance of the issue. Upon recent review of figures collated by the CDC, they found that figures collected by the Red Cross charity had considerably more incidents, and more thorough information on the cases. This was due the close proximity in which the Red Cross works with the victims, and their ability to gain qualitative data. The CDC has found such data very valuable and intends to include Red Cross services and data more frequently. (Noa, 2016). The UK has several charity groups that work with victims and specifically in relation to carbon monoxide poisoning. These charities would be well placed to gain additional qualitative data on the CO poisoning incident.

Charities that have direct contact with victims of carbon monoxide poisoning are in a good position to collect valuable qualitative incident data to complement the pre-existing quantitative data available. Such groups should be approached to collate and share this data on carbon monoxide poisoning to improve the picture of the impact of CO poisoning in the UK, for the future prevention of incidents.

3.2.4 Conclusion

The numbers of individuals affected by carbon monoxide annually is unknown and the estimates are thought to depreciate the true numbers of individuals affected both acutely and chronically. There are many reasons why we do not know the true numbers of individuals affected by carbon monoxide including misdiagnosis and the disparate way data on CO poisoning incidents is collected, utilising multiple organisations and inclusion criteria. In order to fully recognise the impact of carbon monoxide poisoning on the population of the UK, the many sets of statistics on CO incidents should be collated by one institute, and analysed regularly.

3.2.5 Recommendations

- All data sets on carbon monoxide poisoning incidents should be collated and reviewed for more definitive suggestions of numbers of individuals affected.
- Considering the difference in inclusion criteria for the pre-exiting data sets, any missing data should also be collected; relevant proposals should be drawn for their inclusion by currently included institutions or new organisations to undertake the work.
- Groups and charities that have unique access to victims or carbon monoxide poisoning should be encouraged to collect more detailed qualitative information, to be added to the collaborative data set.

4 Prevention

Prevention of carbon monoxide poisoning includes both front line defences in the home, the creation of policy and legislation at high levels, and all the awareness raising campaigns in-between. It is the most important part of our fight against CO poisoning morbidity and mortality, the protection of the public, and is heavily influenced by our scientific and statistical understanding of carbon monoxide, already discussed.

The following section of this report on the co+Impact study demonstrates important areas of CO poisoning prevention that are in some way impaired, and the improvement of such could greatly aid the protection of the UK public, from the risk of carbon monoxide poisoning.

Carbon monoxide detectors or alarms are the definitive front-line defence against carbon monoxide poisoning for users. They alert occupants to a carbon monoxide leak and provide time to take action, to prevent harm; whether the threat comes from a source in the home such as the gas fire in the living room, or from an outside source such as the neighbour's boiler through a dividing wall. However, incorrect installation and use of these devises can affect their function, and therefore their usefulness as a life-saving device. More research into use, and how to improve awareness, is necessary to ensure effective operation.

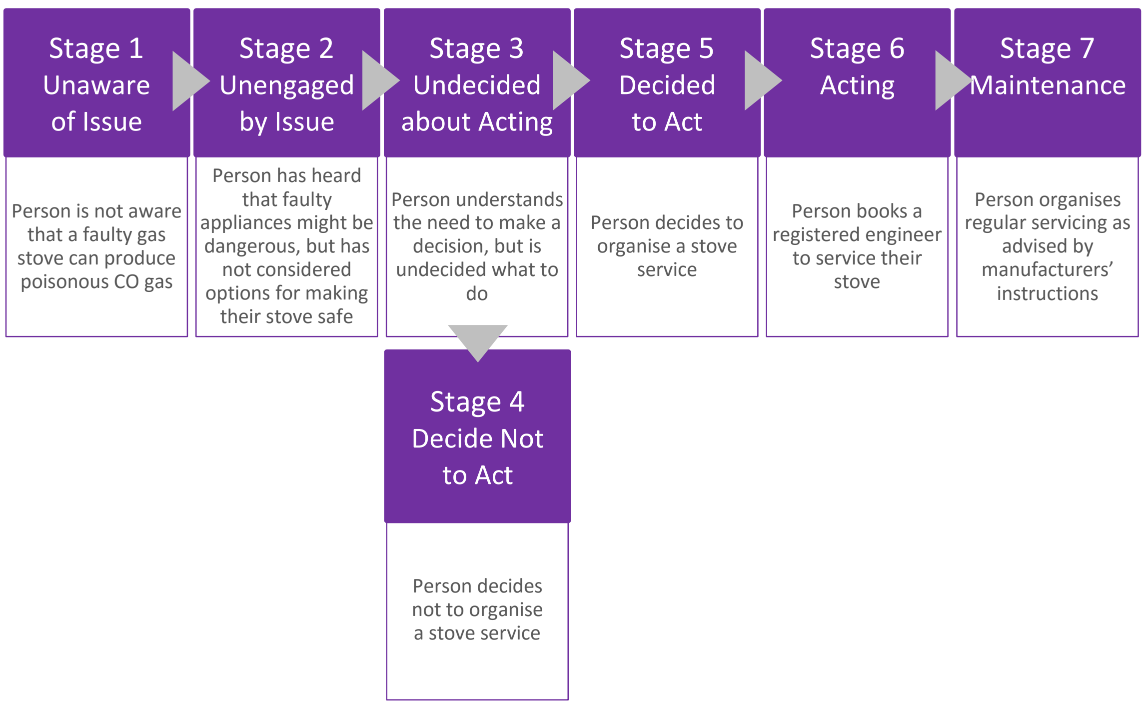
The creation of legislation to protect the UK population from carbon monoxide poisoning is arduous, however, good moves have been made recently in the UK to protect the public. Some of the invested stakeholders in CO are currently passionate but uncoordinated in their efforts and this could be affecting the chances of making effective CO policies. Here, a system dynamic modelling approach is suggested to coordinate groups and drive the creation of policy more purposefully.

This proceeding chapter highlights some important issues in CO alarm installation and use that require more research and better awareness to protect the public from CO. Furthermore, it suggest an in-depth research project and continued framework of groups, for the direction of policy-creation, for the purposes of CO poisoning prevention in the UK.

4.1 Carbon Monoxide Alarm Placement Guidelines

4.1.1 Introduction

The most recent report by the All-Party Parliamentary Carbon Monoxide Group (APPCOG), entitled 'Carbon Monoxide: From Awareness to Action' (APPCOG, 2015) used a social sciences approach to focus on the ability to change the public's behaviours in order to reduce carbon monoxide (CO) related morbidity. The report suggested that there are different phases of behaviour that need to be influenced, to get people to a stage where they are protected from CO (Precaution Adoption Process Model). It proposes that there are specific ways in which these behaviours can be influenced to advance on to a next phase. One of the common methods that appears with regard to changing behaviour, is the relay of information to the public in a myriad of forms from media, individuals, reminders, literature and direct assistance. It was identified in this report that information is critical to getting members of the public to the final behaviour phase ('Maintenance') where they are truly and sustainability being protected from carbon monoxide poisoning. Therefore, the information relayed to the public should be accurate, easily understandable, helpful and expandable to have the greatest effect. However, when it comes to carbon monoxide alarms, the information available to the public with regard to installation, legislation, and maintenance can be difficult to understand and contradictory at times. Furthermore, the maintenance of a carbon monoxide alarm could wrongly be considered the final stage in the protection of an individual or household, while the true last stage is to act on an alarm when it goes off, and to do so in the correct way, which requires a further level of understanding and trust.



4.1.2 Uptake of Carbon Monoxide Alarms

Audible carbon monoxide alarms are recommended for all households to alert individuals of a dangerous or even deadly CO leak in their home. They are considered a secondary defence from carbon monoxide poisoning to the proper maintenance and use of carbon fuel burning appliances, such as an annual boiler check or regular chimney sweeping. Even in buildings without any carbon burning appliances where everything is run solely on electricity, as found in many new builds, a carbon monoxide alarm should still be present. They can also be protective in situations where there is an underground parking structure beneath the residents' home or where adjoining neighbours have a CO leak (from improper use of an appliance for example) and the CO permeates through walls (Vermesi et al., 2015). Since they are small and mobile, CO alarms can be taken on holiday, when the guest would have little to no knowledge and control over heating arrangements.

Krenzelok et al. (1996) found that in the US, audible CO alarms were effective in alerting individuals of a carbon monoxide leak. Incidents where an alarm was present recorded lower CO levels (64.3ppm versus 99.6ppm without), and residents were significantly less likely to be symptomatic and require medical treatment. Audible carbon monoxide alarms are important life saving devices that no home should be without.

CO Alarms	Smoke Alarms
19% APPCOG, 2015	88% DCLG, 2014
31% CORGI, 20	90% CORGI, 2007

The figures for carbon monoxide alarm installation in the UK are considerably lower (19% (APPCOG, 2015), 31% (CORGI, 2007)) than that for smoke alarms (88% (Department for Communities and Local Government, 2014), 90% (CORGI, 2007)). There is, however, no legal requirement for CO alarms in private properties. The relatively low uptake of carbon monoxide alarms can be explained by a multitude of factors including but not limited to:

- the visibility of smoke, its direct link to fire, and the widespread knowledge and intuitive recognition of fire as a physical risk to be prevented, unlike invisible and un-sensible carbon monoxide, which is harder to except as risk;
- the creation of a 'fire kills' campaign strategy with concentrated departmental funding, and a coordinated and easily recognisable brand;
- the common myth in the public domain, that a smoke alarm would protect individuals from carbon monoxide as well.

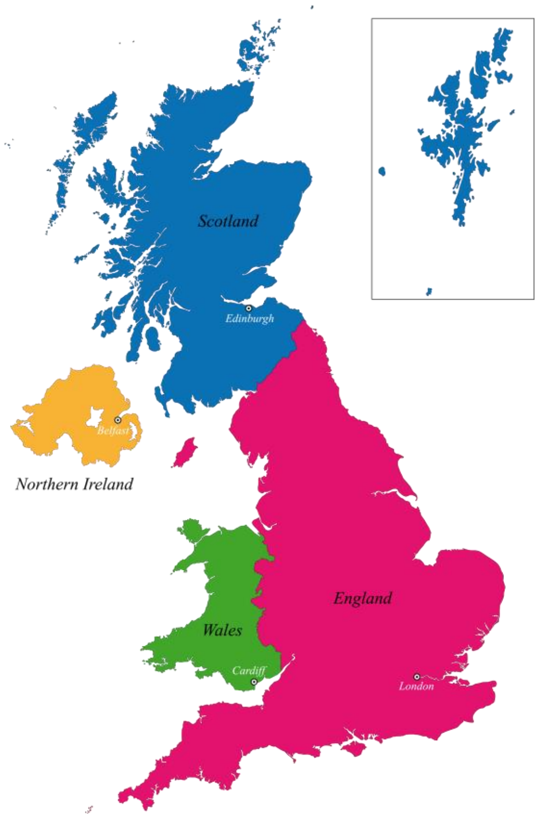
On a positive note, the uptake of CO alarms was previously considerably lower, and has increased in recent years due to the hard work of dedicated individuals, media attention, and charity campaigns; all without the levels of funding or coordination of efforts afforded to fire prevention. However, the installation of carbon monoxide alarms comes with a caveat in that the incorrect placement of an alarm could prevent proper function (Raub et al., 2000; Health and Safety Executive (HSE), 2001a) and incorrect installation of the device can be easily done.

4.1.3 The UK – Many Similar CO Legal Requirements

In October 2015, it became a legal requirement in England and Wales that carbon monoxide alarms be present in privately rented accommodation, where there is a solid-fuel burning appliance (The Smoke and Carbon Monoxide Alarm (England) Regulation, 2015). There has been much discussion of this recently introduced legislation that requires landlords to take action to protect their tenants from carbon monoxide, due to its limitations, and differences to similar laws in the rest of the UK. There are several laws around the United Kingdom and Ireland that differ very slightly, which can be confusing for both residents of these countries and other countries outside the UK looking for examples of effective legislation.

Within the UK, our current laws regarding the provision of carbon monoxide alarms are as follows (CO-Gas Safety, 2015):

- that in Scotland a CO alarm is required to be installed in every space containing a fixed combustion appliance - with the exception of cooking appliances - and where a flue passes through high-risk accommodation (a bedroom or living room).
- In Northern Ireland however, where any combustion appliance is installed, reasonable provision shall be made to detect and give warning of the presence of carbon monoxide gas at levels harmful to people.
- There is no legal requirement for landlords in England and Wales to install alarms where there are only gas appliances but there is, as previously mentioned, a duty for private landlords to fit a CO alarm in a room with a *solid*-fuel appliance (The Smoke and Carbon Monoxide Alarm (England) Regulation, 2015).



- Additionally, there is a duty in England and Wales, under the Building Regulations, to install a CO alarm when a solid-fuel heating system is installed, such as a wood-burning stove (J3, The Building Regulations 2010, 2010). (CO-Gas Safety, 2015).

It may appear that England and Wales' recent addition is lacking somewhat, and compared to the legislation of other parts of the UK, this would be correct. However, the legislation is firstly a step in the right direction, and the decision to limit the reach of the law was based on pre-existing legislation designed to protect tenants from carbon monoxide poisoning from non-solid-fuel burning appliances. This current legislation (for all of the UK), is the requirement for all landlords to perform an annual 'gas safety check' on gas appliances and obtain a certificate as proof for tenants (The Gas Safety (Installation and Use) Regulations, 1998). The new legislation in England and Wales (The Smoke and Carbon Monoxide Alarm (England) Regulation, 2015) is designed to save the lives of approximately eight individuals a year from fatal carbon monoxide poisoning, derived from solid fuel burning appliances (Department for Communities and Local Government, 2015) and based on other studies (Chen et al., 2014). Just the introduction of the legislation may be enough to raise awareness of the issue and save further lives. The impact of this legislation will remain to be seen.

The differences in the laws across the UK are confusing for residents as to whether the law applies to them, and if they have the relevant appliances that the laws makes reference to. The Council for Gas Detection and Environmental Monitoring (CoGDEM) provide a help line (as do other agencies including Public Health England (PHE), CO-Gas Safety and Local Fire Departments) to assist individuals with non-emergency carbon monoxide related issues, such as alarm installation, legislation and other general CO queries. This is discussed in more detail later. Many of the calls CoGDEM receive in particular, are related to confusion over which of the laws apply to the individual (Greenham, 2016). In this instance it can be difficult for those giving advice, as they can easily make assumptions regarding the location of the caller. However, even if the installation of a carbon monoxide alarm is not a legal requirement for the caller, after a one-to-one talk with the advisor, they are likely to purchase a CO alarm anyway, as the cost is minimal, and they are more aware of the risks of CO (Greenham, 2016).

Whereas we must appreciate that right now there a many differences in laws between the countries of the United Kingdom, when it comes to health and safety, the issues are the same and therefore there should not be differences in legislation with regard to these matters. Therefore, all stakeholders should work towards harmonising the laws, regulations, and advice governing carbon monoxide safety.

In the meantime, with regard to the existing differing laws around the UK, for the ease of residents and landlords, there should exist an easily accessible breakdown of the alarm requirements for each country within the UK and Ireland. At this time, the only existing, accessible compilation is hosted by the CO-Gas Safety (CO-Gas Safety, 2015) text on their webpage. More can be done to make the legal requirements clear for individuals and there should be an interactive guide on UK alarm installation, which can be accessed by all.

4.1.4 Incorrect Alarm Installation

The most recent APPCOG report on carbon monoxide (APPCOG, 2015) raised a number of issues regarding the installation of CO alarms, and specifically the issue of CO alarm placement, which is also a topic of discussion for the public. Since the introduction of the 2015 legislation for landlords in England to have CO detectors in certain rented properties (The Smoke and Carbon Monoxide Alarm (England) Regulation, 2015), alarm placement has become a more focused topic for debate. Specifically, discussions have surrounded the use of combination smoke and CO alarms, and the instructions for installation included with the purchase of alarms. Worldwide, confusion exists with regard to the specific laws on CO detection in the home within each country. In Chicago, USA, carbon monoxide alarms are a requirement in homes. However, Rupert et al. (2013) found that many residents did not know where to install their alarm. Furthermore, in their questionnaire, respondents failed to identify simple alarm placement criteria such as positioning an audible alarm where it can be heard (Rupert et al. 2013).

The challenge to get the public to purchase and install CO alarms is a considerable one, but incorrect placement and maintenance could cause CO alarms to have delayed activation and not function correctly, failing to alert the user of a CO leak (Raub et al., 2000; HSE, 2001a), and at the same time giving them a false sense of security.

The correct installation and maintenance of a CO alarm is important to its ability to function well, and alert the owner to the presence of carbon monoxide. Currently in the UK, approximately 19% of homes have a carbon monoxide alarm (APPCOG, 2015), however it has been identified in recent studies that as many as 22% of alarms in residents' homes are incorrectly installed. Naylor et al, (2013) found 24% incorrectly installed, and McCann et al. (2013) found that 11.5% of the alarms in their study on homes in a local housing association were in an unsuitable location. This means that rather than 19% of UK homes being protected, the figure could be below 15%.

Incorrect installation can include but is not limited to:

- being in the wrong location for adequate function,
- without functional batteries, or
- past their working lifetime (about seven years) (HSE, 2011).

Carbon monoxide alarms are sensitive to their location and should not be deployed in environments that are humid, have low air flow (dead air), high air flow (near windows) or extremes of temperature otherwise their activation times can be affected (Raub et al., 2000). According to Naylor et al. (2013) and HSE (2011), the most common example of incorrect deployment of CO alarms (76%) was inappropriate positioning in the room (e.g., wrong height from floor) and in 24% of cases, the alarms were identified as being too distant from potential sources of CO. Furthermore 6% of the alarms had absent or drained batteries (Naylor et al., 2013). The worrying lack of working CO alarms brings to attention an issue of continued maintenance and testing of alarms, once the battle to get the public to purchase and install an alarm has been won.

The reasons why an alarm without batteries or being past its lifetime, would not functioning correctly, are more obvious than an alarm installed in the incorrect location. Admittedly the tag-line, 'the worst place for a carbon monoxide alarm to be is in the box' stands true. However, studies and anecdotal evidence from those in the industry suggest, that a functioning alarm located in the wrong place in a home may not activate during a CO leak of a level considered harmful (Raub et al., 2000; HSE, 2001a). The HSE report (2003) outlines four incidents where individuals, some requiring hospital treatment, were poisoned by CO, after operational CO alarms failed to activate during a CO leak due to incorrect placement.

On the other hand, there has (thankfully) never been an instance where a fatality has occurred from carbon monoxide poisoning, because an alarm did not activate due to it being incorrectly located (Greenham, 2016). A CO alarm is still likely to activate before CO reaches life-threatening levels in a living environment, even if positioned in a less than optimal place.

Nonetheless, information on the location and positioning of carbon monoxide alarm should be clearly disseminated to the public along with general information on carbon monoxide and the need for detectors (Johnson-Arbor et al., 2012).

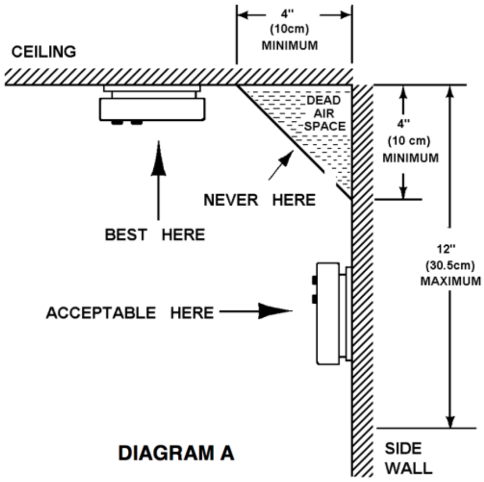
4.1.5 No 'One-Answer'

Current alarm installation guides suggest that an alarm should be positioned one to three metres away from a potential source of carbon monoxide (a fuel burning appliance), on a wall and at a height just below the ceiling height e.g. the top of a doorframe (BSI, 2013a, 2013b).

However, there exists much variation in the installation information available to the public:

- What number of CO alarms should be in a household?
- should there be one outside sleeping areas?
- Is just one enough?
- What about the risk of leaks form internal flues that go through other rooms?
- And what if you have a house with high ceilings, or the room you have a fuel-burning appliance in is too small for CO alarm to be one to three metres away?
- Do you live in a flat or a semi-detached house where there could be additional risks from adjoining properties?

This suggests that; whereas CO alarm installation instructions should be simple and easy to use (APPCOG, 2015), there is no one-size-fits-all answer to correct installation. Usually this would be something for the new owner of a CO alarm to work around. But with the introduction of the new legislation requiring the installation of a CO alarm in any room with a solid-fuel burning appliance in rented accommodation (The Smoke and Carbon Monoxide Alarm (England) Regulation, 2015), there is now a legal requirement to get this right, and the guides can be very difficult to work with, as is currently reflected in landlord discussion forums.



As previously mentioned, the optimal location for a carbon monoxide alarm is one to three meters away from a fuel-burning appliance, positioned on a wall at about doorframe height (BSI, 2013a, 2013b) and in a stable environment (Raub et al., 2000). However, without a one-size-fits-all location this is only an optimal position. In the event that there is not an optimal position available, for example not next to a window or sink etc. then a sensible location should be identified to install a CO alarm. Between the optimal location and the inaccurate locations described in alarm instruction guides, there should be a position within the home where the alarm can be installed and still function to protect the occupier. Johnson-Arbor et al. (2012) suggest that most carbon monoxide poisoning fatalities occur in the home setting while the occupants are asleep, which advocates the installation of CO alarms near sleeping areas. But only 17.2% of their US sample had an alarm installed close to a bedroom, which they advise, can be improved through increased public awareness of alarm location requirements. However, in the UK, such a location is not primarily advised by legislation nor alarm installation guidelines. HSE 2001b found that moving an alarm from an optimal position high up in a primary room to a less favorable location, such as another room or lower in a primary room, reduced an alarms function by 25-30% and increased unpredictability of performance.

There are instances where the installation instructions supplied with a carbon monoxide alarm may be ignored such as the installation of a CO alarm in a bathroom. The EN 50292 (BSI, 2013b) standards for CO alarms (reflected in installation guides) state that a CO alarm should not be installed in bathrooms, as they are considered a damp/steamy environment that is not suitable for the functioning of electronics. However, installation guides state that a CO detector should be placed in the same room as a fuel-burning appliance. This creates an argument for the optimal versus sensible positioning of a CO alarm. If the bathroom has a fuel-burning appliance installed, which is a possibility, according to the regulations, the CO alarm should be installed in the bathroom also. If the alarm were to be positioned outside of a bathroom, this would be against the regulations but within reason. However, if the alarm is installed outside the bathroom there is chance that it may not activate rapidly enough, as the CO would have to permeate through walls, or through an open door, before activating the alarm, placing anyone in the bathroom at the time the appliance is in use, at risk. Therefore, it is advised that in this instance that the CO alarm be installed in the bathroom, providing that the bathroom is being used in a normal way (for showers/baths, and ventilated and without excessive dampness) (Greenham, 2016). This is information that is available to customers should they choose to call a helpline such as CoGDEM for advice. However most other helplines will not be able to assist in these instances as they advise looking back at the installation instructions included with the alarm. The alarm specific instructions do not include this information, which is acceptable when the need for simplicity and attractiveness for guides is considered. Although this information is both important and relevant, the installation guides included with CO alarms may not be the best place to relay it. Installation guides in general, especially if they seem complicated and/or when they have large amount of small-font text, are often ignored. This is particularly true for tasks that appear to be simple. There should be other ways of getting this information out to everyone who needs it; and its provision should not be dependent on which helpline is being called. It is a legal requirement in several instances around the UK that CO alarms be present in homes, if these laws are to be expanded to protect more individuals, then the advice and assistance for installation must be improved first.

It can be tempting for individuals to install combination smoke and carbon monoxide alarms, especially for landlords who must now install both in England and Wales, due to the new legislation (The Smoke and Carbon Monoxide Alarm (England) Regulation 2015). However, a smoke alarm and a CO alarm should be positioned in different in locations. A CO alarm should be on a wall opposite an appliance, 1-3 metres away, and at about doorframe height, whereas a smoke alarm should be positioned on the celling at the highest point. As tempting as it is to purchase a combination alarm, these are advised only for positioning in boats for example, where ceilings are lower than average, and rooms are small with multiple functions. Carbon monoxide alarms and smoke alarms can still be purchased together in packs that include two separate alarms. This kind of information should be made clearer for customers as combination alarms are not advisable in most situations.

The standards for CO alarm manufacture and testing are described in EN 50291 (BSI, 2013a) and EN 50292 (BSI, 2013b) and include (but is not limited to) such information as construction requirements, instruction booklet requirements, performance, installation location, advice for users and emergency actions. In addition, there is a contradictory premise present here between testing, and installation. The installation instructions suggest that a CO alarm should be positioned on a wall just lower than ceiling height. However, during a manufacturer's standard 'drop test', a carbon monoxide alarm is only required to survive a fall of one metre. It appears counterintuitive for an alarm to be required to be placed up high, based on research and included within the alarm standards themselves, if it is not required to survive a drop from the same height. If the optimal position for a CO alarm is more than one metre high then the alarm should be required to still be functional after a fall from this height.

Another issue between CO alarms and their standards is the lack of a suitable alarm, and corresponding standard, for installation in a place of business. Currently the standards discussed above are for small, domestic alarms only. There also exist alarms and corresponding standards for industrial alarms for large businesses with obvious sources or carbon monoxide for example. However, there are no carbon monoxide alarms for places of business such as offices, where there are multiple individuals, and for example, the possibility of a small kitchenette, nor standards that allow for the innovation of such alarms. In these sorts of environments, a domestic alarm would be suitable in size for the risk and required audible level. But according to the standards, they are only for domestic premises. This is an issue as people spend much of their time at work, and the same risks are still present, as at home, therefore alarms should exist for this type of premises. Support for such an action would be readily available if we consider the types of environments that would be included in such a definition, such as schools as one example. CO alarms are advised in schools under BB101 (2006), with no legal requirement, however there have been several cases of acute CO poisonings in schools where thankfully no one was harmed. Children are considered a more at-risk group to CO poisoning than normal healthy adults so CO alarms should be present in schools, however there is technically no CO alarm available to install here. Furthermore, these 'occupational environments' are likely to have pre-existing wired-in smoke alarm systems (possibly with heat sensors also), so optimal CO detection devices innovated for these spaces would ideally fit into an existing system. One alarm manufacturer (AICO) does produce a smoke and CO alarm system with radio link technology, which would be ideal for such environments. However, they are still considered domestic alarms, and not technically deployable in office, school, or small business situations.

4.1.6 Alarm Instruction Guides

The 2015 APPCOG report recognised the issue of incorrect alarm placement and maintenance, and suggested that alarm installation guidelines included within the alarm packaging are confusing. The report made a recommendation that the guides be improved to be more 'user-friendly', with clearer descriptions and the use of graphics. This would increase the likelihood that the guides would be used to install the alarms, and that the alarm would be installed correctly. At this time, the APPCOG has been assured that steps have been taken towards this direction, and alarm manufactures are already in the process of meeting this recommendation with the use of step-by-step installation graphics etc. Whether the introduction of such assistance with installation will in fact increase the percentage of CO alarms correctly installed with regard to location, and whether they are consistently maintained will remain to be seen.

Often people become confused by the alarm installation instructions and are unsure of where to install their carbon monoxide alarms; they contact a number of different departments including Public Health England, their local Fire Department and CoGDEM. Considering the differences in alarm manufacturers and the risks associated with incorrect installation, PHE for example will refer the user back to the alarm installation guidelines provided with the alarm. Cornwall Fire and Rescue Service (Oral Evidence cited in APPCOG, 2015) also use this as their go-to process, except in the case of elderly or confused members of the public. In these instances, they will attend the house and sit with the resident, go through the instructions, and work with them to position the alarm in the best location. Only in the case of very elderly individuals will they install the alarm for them, considering this to be the safest option (Oral Evidence cited in APPCOG, 2015).

CoGDEM offer a lot of advice on carbon monoxide alarm installation to callers of their helpline. In cases where individuals have unconventional houses, where it may not be immediately apparent where the optimal position for a CO alarm is, CoGDEM work with the individual to correctly position the alarm. Like Cornwall Fire and Rescue Service, their most common calls however are the elderly who cannot translate the instructions to how it may apply to their home. In CoGDEM's attempt to make advice as simple and easy to understand, they utilise three main points to convey to callers:

- if positioning proximal to an appliance, place it up high;
- if positioning within a bedroom, place it at sleeping height; and
- lastly that CO is usually released during combustion which will cause it to rise initially.

The APPCOG report (2015) also discussed the public culture whereby instructions for the installation and use of home devices are not read; people do not read them as they think they do not need to. Therefore, installation instructions need to be made as simple and inviting as possible. This is being currently improved by alarm manufactures that are introducing graphics to illustrate alarm activation, positioning and maintenance.

Many people can probably relate to not understanding the instructions to a new purchase, and with information and guides so easily available online, this is where many will turn. Like with many devices, there exists a multitude of instruction online for the installation of carbon monoxide alarm. However, there is also a lot of incorrect information out there, in easily accessible and frequently utilised sites, such as YouTube. These inaccurate videos and guides transfer some incorrect information such as the density of CO being greater than that of air, and therefore suggesting the installation of carbon monoxide alarms close the ground. The USA is a frequent distributer of this kind of information; alarms that plug directly in to the mains are common, and this facilitates their location at lower levels in the home. However, CO is in reality the same density as air, and mixes equally following an initial rise to ceiling height upon production, as a result of its release with heat (HSE, 2001b). Due to the ease-of-use and freedom of the Internet, this information is still easily accessible here in the UK and can be used by individuals to install their carbon monoxide alarms, should the guides be too confusing, or if they feel they do not need to utilise alarm specific guides.

4.1.7 Emergency Action to a Sounding CO Alarm

The APPCOG report (2015) suggests that the final stage in the action process model, to protect the public from carbon monoxide poisoning is maintenance; for example, regular boiler servicing, chimney sweeping or the testing and battery replacement in CO alarms. However, anecdotal evidence suggests that there is one more stage to protecting individuals that can also be driven by the provision of information: the emergency actions to be taken upon the activation of a CO alarm. Knowing the actions to take and actually taking them when an audible carbon monoxide alarm sounds is influenced by trust in the alarm and the knowledge the individual holds about CO. When a CO alarm activates, a home should be ventilated, evacuated, and the helpline should be contacted; the issue should then be resolved before re-entry of the property. Taking these actions in a timely manner is a final and crucial stage in the protection of individuals from CO. Lack of action to a CO alarm makes the prior stages in awareness, installation and maintenance redundant. Some individuals fail to evacuate and act accordingly, not trusting the alarm for many reasons, often taking the alarm outside to fresh air, removing the batteries or blocking the sound. One of the reasons that people may think that the alarm is false is that it sounds during the night, when their boiler is inactive for example. This stems from a lack of understanding of CO alarms that work by concentration of CO over time. This means that the CO level has to be at a certain level for a length of time before being dangerous to health, and the alarm will sound. Therefore, if a faulty boiler produces CO at a concentration not immediately harmful, the alarm may not activate for an hour or so, and only if the concentration does not decrease. Furthermore, a lack of understanding of the sources of CO and the movement of CO through walls and vents can cause individuals not to react to a CO alarm activation, as they perceive there to be no source of CO. Bizovi et al. (1998) suggest that CO sources are difficult to detect in the home environment by the owner as they are not as obvious as smoke being a cause for smoke alarm activation. However, even if there is no immediately noticeable source of carbon monoxide in the home, the same actions should still be taken as the gas could be coming from an adjoining neighbour, garage, business etc. When carbon monoxide alarms are considered as a protective strategy to CO their uptake does not stop at maintenance as trust in this life saving device (which can be challenging considering the silent/invisible nature of carbon monoxide) is required to move to emergency action. This crucial emergency action phase can be reached through improving the information disseminated to the public and thereby increasing trust.

4.1.8 Conclusion

The uptake of CO alarms by the public has increased in recent years and this has been facilitated by awareness campaigns, media coverage and the introduction of the 2015 legislation requiring landlords to have CO alarms where there are solid fuel burning appliances

(The Smoke and Carbon Monoxide Alarm (England) Regulation 2015). However, this has also raised a number of questions about the placement of audible alarms, which can only be answered though increased research and improvements in the information available to the public. More research should be carried out with regard to the flow of carbon monoxide in normal air during a CO leak. The information provided with CO alarms upon installation should be made clear, and desirable to follow, to prevent adlibbing and the use of incorrect but easily accessible media. The above analysis of carbon monoxide alarm legislation, usage and standards, advocates the following recommendations for research and policy.

4.1.9 Recommendations

- Whilst laws and regulations governing carbon monoxide alarms should be harmonised throughout the United Kingdom, there should be, in the meantime, an interactive repository for the laws on carbon monoxide alarm installation in the UK, which is easily accessible and informative for the public.
- Alarm manufacturers should continue to make installation guides simple for the public to use effectively, and primarily to encourage their use.
- There should be alarm standards for an alarm/system between domestic and industrial for smaller occupational premises.
- If the optimal position for a CO alarm is on average a foot below ceiling height, then carbon monoxide alarms should be drop-tested from an equal height to this.
- There should there be one advice line for CO such as 111 for the NHS.
- Gas inspectors who are already required to ask about whether an individual has a CO alarm (without any legal connotations), should be able to install a CO alarm to optimal positioning and offer this as a service to those without an alarm.

4.2 Agencies of Carbon Monoxide Poisoning: a Participatory System Dynamics Approach

4.2.1 Introduction

Recent changes in legislation and moves to combine efforts to prevent carbon monoxide (CO) poisoning internationally, suggest that a system dynamics approach should be adopted by carbon monoxide agencies to facilitate the creation of policy and the integration of research.

Currently, with regard to CO poisoning prevention, there is no single agency that 'owns' carbon monoxide poisoning. There are a number of governmental agencies, charities, research initiatives and fuel industries dedicated to keeping the public safe from CO and attempting to reduce poisoning incidents. These groups are invited to meet regularly to discuss policy progress and design recommendations for future actions. They are loosely governed by the All-Fuels Action Forum (AFAF) which combines energy industries, parliamentarians (All-Party Parliamentary Carbon Monoxide Group (APPCOG) that gleans parliamentary support for changes in policy), government departments (Cross Government Group on Gas Safety and Carbon Monoxide Awareness), as well as various other stakeholders, such as researchers. The AFAF is advised by chairs of five other specialist groups (AFAF, 2015):

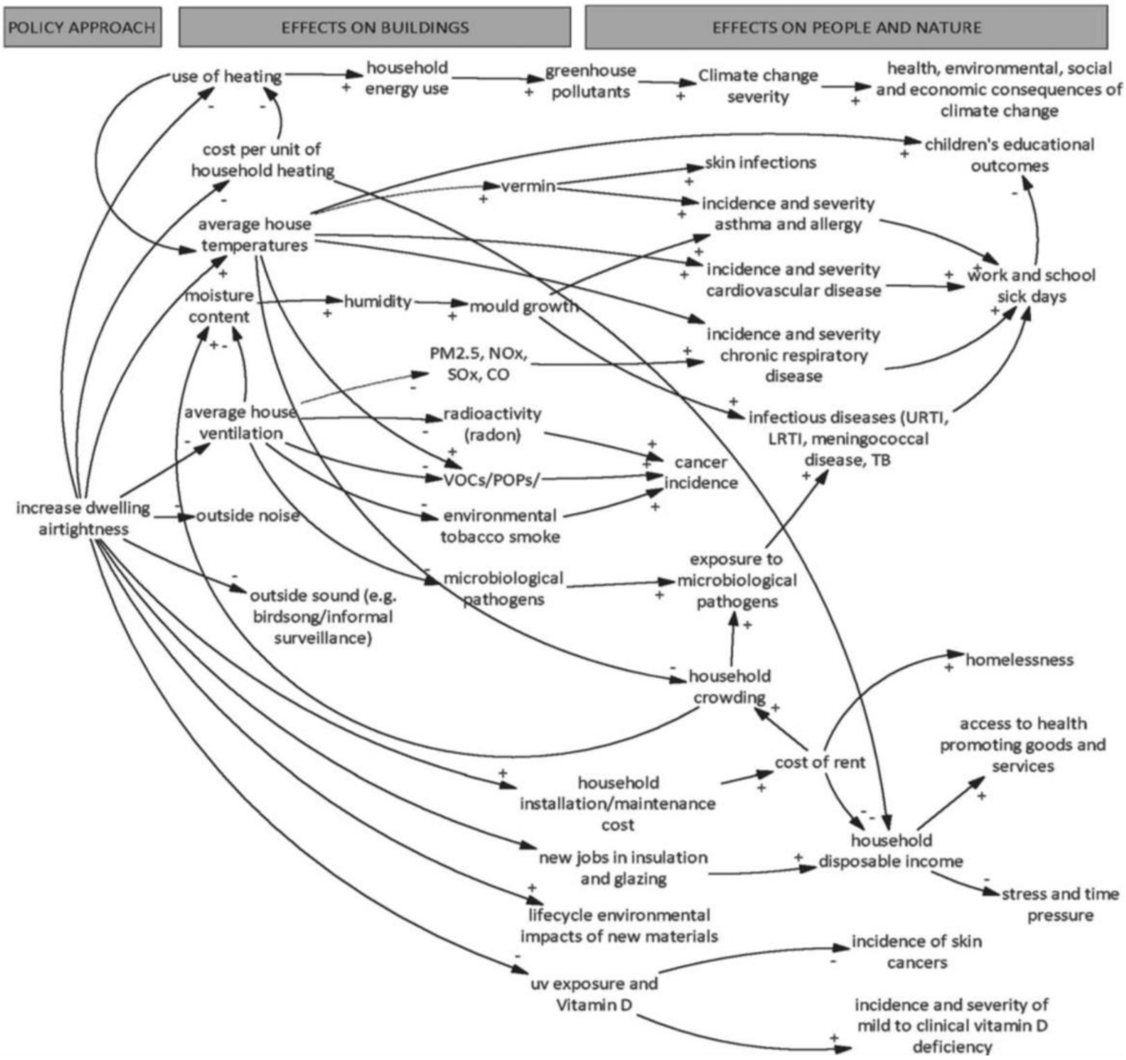
- Medical and Healthcare Professionals;
- Science and Technology (SciTech);
- Helpline;
- Campaigners; and
- Survivors and Victims (SAVi).

Although CO does not have one individual coordinator, this seems a rather organised agency approach. However, the recent change to private landlord legislation came from an agency (the housing sector) who were not initially included in discussions, which highlights the importance of significant groups missing from this structure. Furthermore groups such as Science and Technology, and Helpline, contain a lot of expertise and experience currently not consulted by policymakers as a matter of routine. These sub-groups are fairly recent additions, and there are plans to expand further, connecting with European partners to prevent CO poisoning on an even large scale. However, those larger groups are unlikely to be effective if the UK cannot coordinate all their own groups invested in CO. This situation could be improved though use of system dynamics approach.

4.2.2 System Dynamics for Carbon Monoxide

System dynamics are often used for modelling the impact of the environment and people together to determine the consequences of policy and control measures for example. They engage participants and stakeholders in a decision making process by allowing them to create the model and then test the outcomes of changes. Simple, non-complex maps such as cognitive maps are concept frameworks that demonstrate direct and indirect causality using dynamic holistic systems. System dynamics are a simple-to-use form of semi-quantitative modelling that can be used in a variety of ways, over many topics. (Henly-Shepard et al., 2015).

Participatory system dynamics approaches can be useful for finding leverage points within a system structure that has the potential to change the problematic trend to a more desirable one. They utilise and integrate scientific analysis and stakeholder knowledge to promote learning, facilitate quality decision-making and justifications, and reduce stakeholder conflict by promoting long-term on-goings relationships and increasing social capitol. System dynamics approaches highlight frameworks that are often taken for granted to examine cause and effect relationships and establish potential strategies for making changes to rectify an issue. They can identify solutions that may even be different to what was initially thought to be required. (Stave, 2010). Shrubsole et al. (2014) used a system dynamic modelling approach to analyse the consequences of policies designed to improve energy efficiency in homes. The diagram below maps the links between homes, occupants, agencies, society, and environment with regard to policies on energy efficiency affecting airtightness. These results can be use to ensure policy succeeds, but also that is does not jeopardise health, by highlighting potential trade-offs.



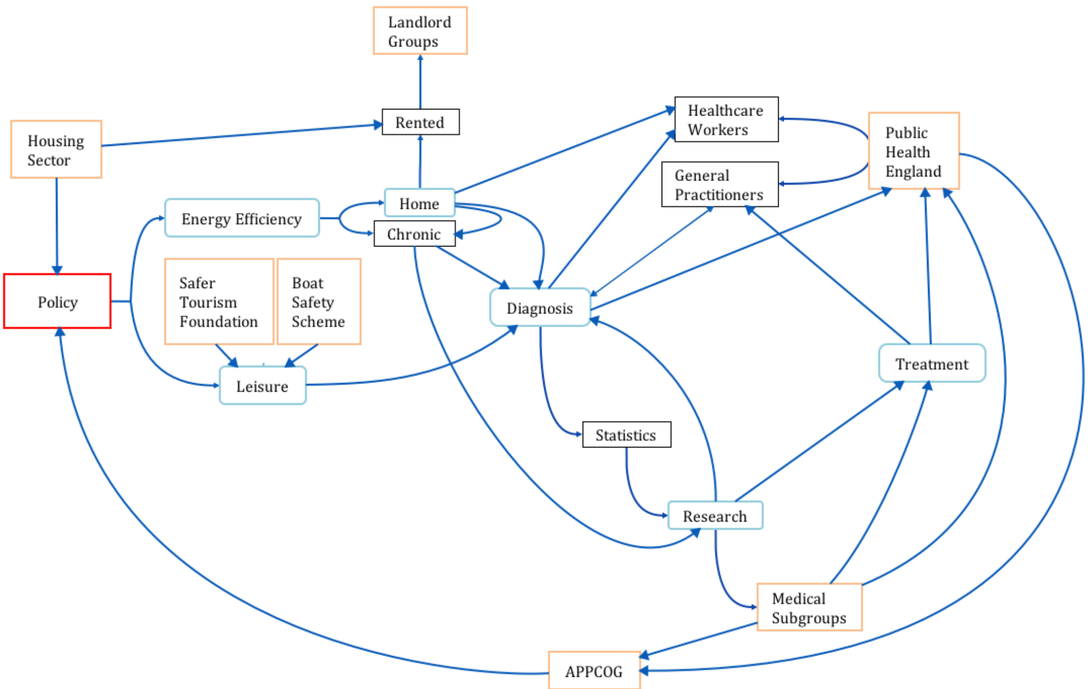
Use of these systems would be of benefit to carbon monoxide research, campaigns, and policy as they are inclusive, transparent and adapt to changing goals and interests of stakeholders. This approach could be used to examine cause and effect relationships between CO and stakeholder agencies, to then identify new solutions to issues regarding CO poisoning prevention and protection. These visual concept maps can highlight new stakeholders and impact, direct our policies and research strategies and provide an adaptive map to our ever-expanding network of stakeholders.

4.2.3 Missing Stakeholders

One of the many benefits of using a system dynamics approach to carbon monoxide poisoning is a thorough review of the current stakeholders, and their relationships with other additional agencies and topics surrounding CO poisoning prevention. The change in legislation for private landlords to install carbon monoxide alarms in rooms where there is a solid fuel burning appliance (The Smoke and Carbon Monoxide Alarm (England) Regulation 2015), came from the housing sector, attached on to a bill requiring the installation of smoke alarms in all rented accommodation. This came as a welcome surprise to other groups involved in CO. However, this agency had not previously been involved in efforts to prevent CO poisoning. This highlighted that there are groups out there with the power to change policy and have great impact in CO poisoning prevention, that were, and are, missing from the current strategies governed by AFAF and APPCOG. A succinct analysis of the current agencies invested in CO research would likely reveal many other groups currently excluded from the mainstream carbon monoxide safety efforts. By examining groups and their relationships with other agencies and departments new areas of interest and impact can be identified and included in discussion. New information can be gleaned on technologies and policies relevant to CO poisoning prevention.

4.2.4 Directed Policy, Research, and Campaigns

There are many benefits to having a participatory system dynamics study in carbon monoxide in the UK. The resulting 'map' of interactions will demonstrate what groups are invested in CO and in which areas they have the most influence. It will display the interactions between the groups, how one may impact another and suggest areas that could make the most impact through policy or research for example. The map will allow a framework for thinking outside the box when it comes to CO poisoning prevention strategies. The image below shows an *example* network that could be created using system dynamics, including current themes, groups and impacts in carbon monoxide to demonstrate what a possible CO agency map would include in its analysis (this is only an example and does not include all groups active in CO research, or their true relationships).



Knowing which current issues in CO have the strongest support, and areas that have the greatest impact is useful for directing the change of policy. Groups that have the most influence can be identified and utilised to make changes to policy and improve legislation to protect the public from carbon monoxide. Not only can these high impact areas be identified, but the consequences of the actions can also be easily established for both the positives and negatives. This would produce a more collated and directed approach to influencing policy in the UK. Not only would the direction of policy for the protection of the public be highly impacted by an agency map produced from such a study, but the research that backs the suggested policies will also be directed and collaborated. The map can be used for decision-making and project planning and a resource for identifying information and related groups for funding and involvement in future projects. The impact of the research and to which area of CO prevention the research is most effective can also be established for the implementation of recommendations and measures to protect the public form CO poisoning.

There is more to an agency map by participatory system dynamics than the agency involved and how they interact with, and influence each other and changes to aid protection. They can also demonstrate the relationships between those groups and external contributing factors such as causes of CO, common locations of incidents, the propensity for data collection, and the consequences of legislative changes. For example, the opportunity for data collection is an important issue and the identification of groups on CO and surrounding topics such as charities, deaths and fuels (for example) could assist in identifying further data available for collation. More available data would provide a more thorough analysis of deaths due to carbon monoxide. These additional groups and topics will inspire researchers and policy makers to think outside the issues of regular agencies and stakeholders to a much broader but comprehensive campaign for CO poisoning prevention.

4.2.5 Taking CO Further

One of the aims of the current CO groups and researchers is that the reach and understanding of carbon monoxide poisoning prevention be expanded to include efforts from across the world, Europe and North America especially. This would be very useful in understanding both similarities and some of the differences that countries face in trying to prevent CO poisoning. New techniques for prevention, protection, technology and treatment can be researched, and shared faster and easier which would be beneficial to everyone. In direct relation to the co+Impact study, for other countries without an established agenda for prevention and control of poisonings, this would be an excellent place to start to determine the main knowledge they hold, and issues they face in CO. However, if the many agencies and groups of the UK are to be joined with those of other countries in Europe, then the UK should have a solid understanding of its invested agencies and stakeholders. This would maintain a strong reliable front for European interactions, increase trust from international partners and assist the flow of information in both directions. Corresponding groups in other countries would also be more easily identifiable from the existing UK framework and this would create a very directed approach to changing legislation in the EU and wider. An agency map of CO stakeholders and their impacts as identified by participatory system dynamics would be of benefit to the UK carbon monoxide strategy. But most importantly this must be understood before more in-depth discussions on CO with European partners, or we are at risk of complicating the situation, and misunderstanding relevant agencies and investors.

Much talk regarding the future of CO is around the lack of one governing body or focal point for carbon monoxide, unlike other public protection campaigns. Large, national campaigns, such as fire safety or cancer research, have shown that the concentration of efforts into one outlet and campaign brand, can have extremely beneficial outcomes. Fragmentation of efforts, budgets, and messages, as exist at the moment, will always limit campaigns and their impact on public safety.

It is often suggested that CO should have one coordinating individual or one governing body to take the topic on, and push for changes to protect the public. This would provide:

- one point of contact for carbon monoxide prevention,
- one group or individual to coordinate the efforts of many,
- it would concentrate resources,
- prevent competing campaign ‘brands’ or contradictory messages, and
- to ease the understanding of CO for the public and parliament.

However, in either of these scenarios, the existing groups and charities etc. and the industry stakeholders will all still be present, active in the campaigns, and adding their unique identities to the overall effort. Therefore, these additional agencies and those created during any possible moves to departmentalise CO, will still need to be closely coordinated. The impact of these agencies and their knowledge on the various topics surrounding carbon monoxide will not be diminished. The campaign to keep the UK population safe from CO will still require these groups and their expertise to make a difference.

It is clear then that despite talk of a single point of contact for CO, which would be most beneficial, there will still need to be contact and coordination of these groups. This would be best accomplished where there is an identifiable network of charities, researchers, departments, and industry stakeholders in CO and wider topics. Categorically, the agency map would be a critical and necessary part of the reorganisation of CO prevention, as it would make clear the network that the single agency is to govern, and how best to do so.

4.2.6 Conclusion

There are several possible options put forward here that may become reality after a participatory system dynamics review. The latest APPCOG report (2015), quite explicitly focuses on the Fire & Rescue Services as an ideal lead, and names several strong arguments. While this may well be a likely ideal outcome, it would be well worth applying the principles of the participatory system dynamics review first.

Whether the prevention of CO poisonings is governed by AFAF, an individual coordinator, the Fire & Rescue Services, or one appointed governmental agency, the current system of agencies will continue to exist, and needs to be better coordinated. A participatory system dynamics approach to carbon monoxide poisoning prevention would identify invested agencies, how they effect and impact each other, areas where policy could be influenced easiest, agencies that can collaborate and that can have the biggest impact on public behaviour for safety campaigns. These benefits would lead to a stronger stance from CO when trying to influence legislation and a more coordinated effort to public safety and awareness. Not only would this be a good approach for CO to adopt but it would also be beneficial to do it now, before international partners are collaborated with. The UK should be aware of its own networks and impacts before coordinating with intentional agencies.

4.2.7 Recommendations

- A system dynamics study should be conducted to determine the current invested agencies in carbon monoxide poisoning prevention, and coordinate them and their impacts.
- The study should engage with the current groups on CO to determine how they interact and impact each other and themes surrounding CO in order to create an agency map.
- The agency map should be used to facilitate the inclusion of groups at meetings etc. and drive with direction and ease, research and policy in specific themes on CO.

5 Summary

In conclusion, the co+Impact study identified several issues with our current understanding and research into carbon monoxide poisoning. The symptoms experienced by victims of CO poisonings are sufficiently variable and non-correlating with COHb, therefore symptomology, not COHb should be used for poisoning determination and severity categorisation, or it can lead to the exclusion of many low-level poisoning incidents in research. Categorising incidents is useful for research; a valuable way of dividing cases by duration and concentration of exposure is *chronic* verses *acute* poisonings as they are significantly different with regard to prevention, treatment, outcomes and diagnosis. Carbon monoxide poisoning incidents in leisure environments are unlikely to have a significant impact on the UK population, but lack available statistics and research to determine the true extent of this issue. Also, research into CO poisoning in leisure environment will strengthen our understanding of CO poisoning in homes, and vice versa. Therefore, neither area of research should be neglected. Due to the move towards increased energy efficiency of UK homes, increasing airtightness and reducing ventilation and permeability, harmful pollutants are building-up in the home environment. A future of increased airtightness in dwellings is set to exacerbate the already harmful and little understood situation of carbon monoxide poisonings. Not enough is known about the health effects of carbon monoxide and even less on how this is will be affected by reduced ventilation.

The International Classification of Diseases system (ICD) is used to track morbidity and mortality statistics, and make international comparisons on diagnostics and data collection. The ICD-10 code for carbon monoxide poisoning lacks information about cause of release, and more overlap exists between fires and CO than is recognised by CO researchers, causing important fire-related CO deaths to disappear from both statistics and CO research. The numbers of individuals affected by carbon monoxide annually is unknown and the estimates are thought to depreciate the true numbers of individuals affected. This can be due to the disparate way data on CO poisoning incidents is collected, and it is suggested here that the many sets of statistics on CO incidents should be collated by one institute, and analysed regularly.

The uptake of CO alarms by the public has increased in recent years, however; this has also raised a number of questions about the placement of audible alarms. The information provided with CO alarms upon installation should be made clear, and desirable to follow, to prevent adlibbing and the use of incorrect but easily accessible media.

The current system of agencies on CO needs to be better coordinated. A *participatory system dynamics approach* to carbon monoxide poisoning prevention would identify invested agencies and how they impact each other. This would lead to a stronger stance when trying to influence legislation and a more coordinated effort to public safety, and it should be adopted soon before international partners are collaborated with.

The co+Impact report has presented the findings of a two-year study to determine the impact of carbon monoxide poisoning on the UK population. It has covered a variety of topics and issues on CO and has further outlined suggestions made by the project, to remedy these issues. The co+Impact study was initially proposed due to an identified deficiency of knowledge on carbon monoxide poisoning coupled with a parallel, unintentional, deficit in the sharing of information between stakeholders. In addition, the impact of carbon monoxides poisoning on the population of the UK, in both domestic and recreational environments, is unknown. The aim of this project therefore, has been to review the current knowledge on carbon monoxide poisoning to determine our current level of understanding on CO, and then identify the gaps that could be improved with future research. The report reviewed many topics on carbon monoxide poisoning research, statistics, and prevention, and there are still many more areas that are highly relevant, that have not been able to be addressed here. From this review, the report then suggested a number of recommendations for research studies and actions for campaign and policy. The purpose of this report was to present the results of the co+Impact study and the recommendations for future research that have been made; the results of this study and the recommendations made can be used to guide future research, improving our understanding of the impact of CO on the UK population.

The results of these directed studies will improve the arguments made for campaigns, changes in behaviour of individuals, and the creation of policy, to protect members of the UK public from the dangers of carbon monoxide poisoning. For this to happen, these studies need to be taken on by funders and researchers in CO, in collaborative efforts, such that the understanding of carbon monoxide can be improved. The co+Impact study has been a useful tool to establish the current state of knowledge on carbon monoxide here in the UK and determine the direction of future research. This kind of study could easily be reproduced in other countries intending to reduce the impact of CO poisoning on their own populations, and establish their own level of understanding, issues, and recommendations for research, which are presumed to be different based on difference in weather, geography and culture. The future path of carbon monoxide research has been suggested here, but in the long-term, the future of carbon monoxide poisoning prevention remains to be seen.

6 Closing Remarks

The co+Impact report has presented here the work of a two-year study into the impact of carbon monoxide poisoning in the UK; a summary of current issues, and following recommendations to rectify them.

The study found that there were many gaps in our current understanding of carbon monoxide poisoning, from diagnosis categorisation, the future effects if energy efficiency, our data collection, and even our prevention efforts. Recommendations for research and actions have been devised during this study, as well as the CO portal, all to aid future projects.

Figures of 40 people a year dying and 200 requiring medical attention in the UK for carbon monoxide poisoning are reported. However, these number are thought to be highly underestimated. Many more are expected to be suffering with the effects of chronic low-level exposures in the home. Determining the true impact of carbon monoxide poisoning in the UK will improve future research, campaigns for prevention, and the creation of policy.

The work of Cranfield University is expected to continue in the topic of carbon monoxide, undertaking future research project and PhD studies, with the goal of protecting the public from CO. Furthermore, the results of this study offer many opportunities for collaborative research projects with other stakeholders. This begs the question, where to next with carbon monoxide?

7 References

All-Party Parliamentary Carbon Monoxide Group (APPCOG). 2015. *Carbon Monoxide: From Awareness to Action.* London: APPCOG

Afsset Working Group on "Indoor Air Quality Guideline Values" (Afsset), 2007. *Indoor Air Quality Guideline Value Proposals: Carbon monoxide.* Maisons-Alfort: Afsset

Anderson, R. A., Watson, A. A., and Harland, W. A., 1981. Fire Deaths in the Glasgow Areas: II the Role of Carbon Monoxide. *Medicine, Science and the Law.* 21 (4), pp. 288-294

Ball, L. B., Steven C. Macdonald, S. C., Mott, J. A., and Etzel, R. A., 2005. Carbon Monoxide-Related Injury Estimation Using ICD-Coded Data: Methodologic Implications for Public Health Surveillance. *Archives of Environmental and Occupational Health.* 60 (3), pp. 119-127

Basarab, M., Leonardi, G. S., and Ruggles, R., 2008. Carbon monoxide: elements of environmental public health surveillance. *Chemical Hazards and Poisons Reports.* 13, pp. 14-17

Bennetto, L., Powter, L., and Scolding, N. J., 2008. Accidental Carbon Monoxide Poisoning Presenting Without a History of Exposure: A Case Report. *Journal of Medical Case Reports.* 2 (118), pp. 1-4

Bernstein, J. A., Alexis, N., Bacchus, H., Bernstein, I. L., Fritz, P., Horner, E., Li, N., Mason, S., Nel, A., Oullette, J., Reijula, K., Reponen, T., Seltzer, J., Smith, A., Tarlo, S. M., 2008. The Health Effects of Nonindustrial Indoor Air Pollution. *Journal of Allergy and Clinical Immunology.* 121 (3), pp. 585-591

Bizovi, K. E., Leikin, J. B., Hryhorczuk, D. O., and Frateschi, L. J., 1998. Night of the Sirens: Analysis of Carbon Monoxide–Detector Experience in Suburban Chicago. *Annals of Emergency Medicine.* 31 (6), pp. 737-740

Bowes, P. C., 1979. Causalities Attributed to Toxic Gas and Smoke at Fires: a Survey of Statistics. *Medicine, Science and the Law.* 16 (2), p. 104-110

Braubach, M., Beaton, A. A. M., Lauriou, S., Heroux, M.-E., and Krzyzanowski, M., 2013. Mortality associated with Exposure to Carbon Monoxide in WHO European Member States. *Indoor Air.* 23, pp. 115-125

British Standards Institute, 2013a. BS EN 50291-1/2:2010+A1:2012. Electrical Apparatus for the Detection of Carbon Monoxide in Domestic Premises Parts 1+2. London: BSI

British Standards Institute, 2013b. FprEN 50292:2013 Electrical Apparatus for the Detection of Carbon Monoxide in Domestic Premises, Caravans and Boats – Guide the Selection, Installation, use and Maintenance. London: BSI

Brown, T., Holmes, P., and Harrison, P. T. C., 2010. The Applicability of Epidemiological Methods to the Assessment of the Risks to Human Health of Indoor Air Pollution: a Review. *Indoor and Built Environment.* 19 (3), pp. 311-326

Budds, J., Biran, A., and Rouse, J., 2001. What's Cooking: a review of the health impacts of indoor air pollution and technical interventions for its reduction. Leicestershire: WELL

Carbon Monoxide All Fuels Action Forum (AFAF), 2015. *Members Activity Report.* London: AFAF

Chaturvedi, A. K., Smith, D. R., and Canfield, D. V., 2001. Blood Carbon Monoxide and Hydrogen Cyanide Concentrations in the Fatalities of Fire and Non-Fire Associated Civil Aviation Accidents, 1991-1998. *Forensic Science International.* 121, pp. 183-188

Chavouzis, N., and Pneumatikos, I., 2014. Carbon Monoxide Inhalation Poisoning. *PNEUMON.* 27 (1), pp. 21-24

Chen, H. T., Yip, F., Lavonas, E. J., Iqbal, S., Turner, N., Cobb, B., and Garbe, P., 2014. Using the exhibited generalization approach to evaluate a carbon monoxide alarm ordinance. *Evaluation and Program Planning.* 47, pp. 35-44

Chiew, A. L., and Buckley, N. A., 2014. Carbon Monoxide Poisoning in the 21st Century. *Critical Care.* 18 (221), pp. 1-8

Clinch, J. P., and Healy, J. D., 2000. Cost-Benefit Analysis Of Domestic Energy Efficiency. *Environmental Studies Research Series (ESRS) Working Paper*. Department of Environmental Studies: University College Dublin

Clower, J. H., Hampson, N. B., Iqbal, S., and Yip, F. Y., 2012. Recipients of hyperbaric oxygen treatment for carbon monoxide poisoning and exposure circumstances. *The American Journal of Emergency Medicine.* 30, pp. 846-851

Cobb, N., and Etzel, R. A., 1991. Unintentional Carbon Monoxide-Related Deaths in the United States, 1979 Through 1988. *Journal of the American Medical Association.* 266 (5), pp. 659-663

CO-Gas Safety, 2015. *Law on CO Alarms.* [online] Available at: http://www.co-gassafety.co.uk/about-co/law-on-co-alarms/ [Accessed 13 April 2016]

Committee on the Medical Effects of Air Pollutants (COMEAP), 2004. *Guidance on the Effects on Health of Indoor Air Pollutants.* London: Department of Health

Council for Registered Gas Installers (CORGI), 2007. *CORGI Carbon Monoxide Report.* London: CORGI

Crawford, R., Campbell, D. G. D., and Ross, J., 1990. Carbon Monoxide Poisoning in the Home: Recognition and Treatment. *BMJ.* 301, pp. 977-979

Cross Government Group on Gas Safety and Carbon Monoxide (CO) Awareness (CGG), 2015. *Annual Report 2014/15.* London: CGG

Croxford, B., Leonardi, G. S., and Kreis, I., 2008. Self-Reported Neurological Symptoms in Relation to CO Emissions due to Problem Gas Appliance Installations in London: a Cross-Sectional Survey. *Environmental Health.* 7 (34), pp. 1-6

Croxford, B., 2007. *Gas Appliance Check Project.* London: University Collage London

Das, P., Chalabi, Z., Jones, B., Milner, J., Shrubsole, C., Davies, M., Hamilton, M., Ridley, I., and Wilkinson, P., 2013. Multi-Objective Methods for Determining Optimal Ventilation rates in Dwellings. *Building and Environment.* 66, pp. 72-81

Davies, M., Ucci, M., McCarthy, M., Oreszczyn, T., Ridley, I., Mumovic, D., Singh, J., and Pretlove, S., 2004. A Review Linking Ventilation Rates in Dwellings and Respiratory health: a Focus on House Dust Mites and Mould. *International Journal of Ventilation.* 3 (2), pp. 155-168

Decker, K., 2016. Major Findings and an Evaluation of Maine’s Carbon Monoxide Surveillance System (COPSS) [presentation]. *Centre of Disease Control and Prevention Summit 2016.* Atlanta: CDC

De Juniac, A., Kreis, I., Ibison, J., and Murray, V., 2012. Epidemiology of Unintentional Carbon Monoxide Fatalities in the UK. *International Journal of Environmental Health Research.* 22 (3), pp. 210-219

Department for Communities and Local Government, 2015. *Review of Property Conditions in the Private Rented Sector: Government Response.* London: Department for Communities and Local Government

Department for Communities and Local Government, 2014. *Fire Statistics: Great Britain April 2013 to March 2014*. London: Department for Communities and Local Government

Dianat, I., and Nazari, J., 2011. Characteristics of unintentional carbon monoxide poisoning in Northwest Iran – Tabriz. *International Journal of Injury Control and Safety Promotion.* 18 (4), pp. 313-320

Duenas-Laita, A., Ruiz-Mambrilla, M., Gandia, F., Cerda, R., Martin-Escudero, J. C., perez-Castrillon, J. L., and Diaz, G., 2001. Epidemiology of Acute Carbon Monoxide Poisoning in a Spanish Region. *Clinical Toxicology.* 39 (1), pp. 53-57

Dutton, S. J., Hannigan, M. P., and Miller, S. L., 2001. Indoor Pollutant Levels from the use of Unvented Natural Gas Fireplaces in Boulder, Colorado. *Journal of the Air and Waste Management Association.* 51, pp. 1654-1661

Fisher, D. S., Bowskill, S., Saliba, L., and Flanagan, R., J., 2013. Unintentional Domestic Non-Fire Related Carbon Monoxide Poisoning: Data from Media Reports, UK/Republic of Ireland 1986–2011. *Clinical Toxicology.* 51, pp. 409-416

Fisher, D. S., Leonardi, G., and Flanagan, R. J., 2014. Fatal Unintentional Non-Fire-Related Carbon Monoxide Poisoning: England and Wales, 1979–2012. *Clinical Toxicology.* pp. 1-5

Garrard, A., 2015. *Exposure Versus Poisoning: What's the Difference?* [online] Available at: <http://www.wapc.org/exposure-versus-poisoning-whats-the-difference/> [Accessed 02 June 2016]

Ghosh, R., Close, R., McCann, L. J., Crabbe, H., Garwood, K., Hansell, A. L., and Leonardi, G., 2015. Analysis of Hospital Admissions due to Accidental Non-Fire-Related Carbon Monoxide Poisoning in England, between 2001 and 2010. *Journal of Public Health.* pp. 1-8

Girman, J. R., Chang, Y-L., Hayward, S. B., and LIU, K-S., 1998. Causes of Unintentional Deaths from Carbon Monoxide Poisonings in California. *Western Journal of Medicine.* 168, pp. 158-165

Green, E., and Short, S., 1998. *IEH Assessment on Indoor Air Quality in the Home (2): Carbon Monoxide*. Leicester: Institute for Environment and Health.

Green, E., Short, S., Shuker, L. K., and Harrison, P. T. C., 1999. Carbon Monoxide in the Home Environment and the Evaluation of Risks to Health – a UK Perspective. *Indoor and Built Environment.* 8, pp. 168-175

Greenham, L., 2016. *Advice on The Smoke and Carbon Monoxide Alarm (England) Regulation, 2015*. [telephone conversation] (Personal communication, 24 February 2016)

Hall, S., and Pocock, D., 2015. *Measurement of carbon Monoxide Emissions from Domestic gas Appliances at Low Ventilation Rates.* Buxton: Health and Safety Laboratory

Hamilton, I., Milner, J., Chalabi, Z., Das, P., Jones, B., Shrubsole, C., Davies, M., and Wilkinson, P., 2015. Health Effects of Home Energy efficiency Interventions in England: a Modelling Study. *BMJ.* 5, pp. 1-11

Harduar-Morano, L., and Watins, S., 2011. Review of Unintentional Non-Fire-Related Carbon Monoxide Poisoning Morbidity and Mortality in Florida, 1999–2007. *Public Health Reports.* 126, pp. 240-250

Harrison, P., and Holmes, P., 2001. *Indoor Air Quality in the Home: Final Report on DETR Contract EPG 1/5/12*. Leicester: Institute for Environment and Health

Hayton, J., Moseley, J., and Pool, G., 2012. *DIDR Carbon Monoxide Incident Report*. London: Downstream Gas Ltd; The Gas Safety Trust

Health and Safety Executive (HSE), 2011. Domestic Carbon Monoxide Alarms: Long Term Reliability and Use Scoping Study. Buxton: HSE

Health and Safety Executive (HSE), 2003.*Continued Appraisal of Domestic CO Alarms*. Buxton: HSE

Health and Safety Executive (HSE), 2001a. Joint industry project on carbon monoxide issues: Long-term reliability of domestic CO alarms. Buxton: HSE

Health and Safety Executive (HSE), 2001b. Joint Industry Program on carbon monoxide issues: The siting of domestic CO alarms: An analysis of full-scale vitiation tests. Buxton: HSE

Henly-Shepard, S., Grey, S., and Cox, M., 2015. The Use of Participatory Modelling to Promote Social Learning and Facilitate Community Disaster Planning. *Environmental Science and Policy.* 45, pp. 109-122.

Henn, S. A., Bell, J. L., Sussell, A. L., and Konda, S., 2013. Occupational Carbon Monoxide Fatalities in the US from Unintentional Non-Fire Related Exposures, 1992–2008. *American Journal of Industrial Medicine.* 56, pp. 1280-1289

Hill, R. W., and Pool, G. (Advantica Technologies Limited), 2001. Joint Industry Programme on Carbon Monoxide Issues: Experimental Work to Study the Interaction Between Air Extraction Equipment and Open-Flued Appliances - Phase 1. Caerphilly: Health and Safety Executive (HSE)

Homer, C. D., Engelhart, D. A. Lavins, E. S., and Jenkins, A. J., 2005. Carbon Monoxide-Related Deaths in a Metropolitan County in the USA: an 11-year study. *Forensic Science International.* 149, pp. 159-165

House of Commons Environmental Audit Committee, 2010. *Air Quality Fifth Report of Session 2009–10 Volume I.* London: The Stationary Office Limited

Howieson, S. G., Lawson, A., McSharry, C., Morris, G., McKenziw, E., and Jackson, J., 2003. Domestic Ventilation Rates, Indoor Humidity and Dust Mite Allergens – are our Homes causing the Asthma Pandemic? *Building Services Engineering Research and Technology.* 24 (3), pp. 137-147

Howieson, S. G., Sharpe, T., and Farren, P., 2013. Building tight – ventilating right? How are new air tightness standards affecting indoor air quality in dwellings? *Building Services Engineering Research and Technology.* 0 (0), pp. 1-3

Ilano, A. L., and Raffin, T. A., 1990. Management of Carbon Monoxide Poisoning. *CHEST.* 97 (1), pp. 165-169

Iqbal, S., Clower, J. H., Hernandez, S. A., Damon, S. A., and Yip, F. Y., 2012. A Review of Disaster-Related Carbon Monoxide Poisoning: Surveillance, Epidemiology, and Opportunities for Prevention. *American Journal of Public Health.* 102 (10), pp. 1957-1963

Johnson-Arbor, K., Liebman, D. L., and Carter, E. M., 2012. A Survey of r`esidential Carbon Monoxide Detector UtilisationAmong Connecticut Emergancy Department Patients. *Clinical Toxicology.* 50, pp. 384-389

Kao, L. W., and Nanagas, K. A., 2004. Carbon Monoxide Poisoning. *Emergency Medicine Clinics of North America.* 22, pp. 985-1018

Keshishian, C., Sandle, H., Metlzer, M., Young, Y., Ward, R., and Balasegaram, S., 2012. Carbon Monoxide From Neighbouring Restaurants: the Need for an Integrated Multi-Agency Response. *Journal of Public Health.* 34 (4), pp. 477-482

Kirkpatrick, J. N., 1987. Occult Carbon Monoxide Poisoning. *Clinical Medicine.* 146, pp. 52-56

Kleinman, M. T., Davidson, D. M., Vandagriff, R. B., Caiozzo, V. J., and Wittenberger, J. L., 1989. Effects of Short-Term Exposure to Carbon Monoxide in Subjects with Coronary Artery Disease. *Archives of Environmental Health.* 44 (6), pp. 361-369

Krenzelok, E. P., Roth, R., and Full, R., 1996. Carbon monoxide… the Silent Killer with an Audible Solution. *American Journal of Emergency Medicine.* 14 (5), pp. 484-486

Kukadia, V., Liddament, M., Gupta, A., Upton, S., Chan, P., Garvin, S., and Reid, J., 2012. *The Effect that Increasing Air-Tightness may have on Air Quality Within Dwellings.* Livingston: British Research Establishment (BRE)

Mandal, S., Ruggles, R., Leonardi, G., Goodfellow, F., Bradley, N., and Murray, V., 2011. Developing Best Practice Response to Carbon Monoxide Incidents: a Toolkit for Health Protection Frontline Staff. *Public Health.* 125, pp. 148-156

McCann, L. J., Close, R., Staines, L., Weaver, M., Cutter, G., and Leonardi, G. S., 2013. Indoor Carbon Monoxide: A Case Study in England for Detection and Interventions to Reduce Population Exposure. *Journal of Environmental and Public Health.* 2013, pp. 1-5

Mcleod, G., 2013. *Carbon monoxide poisoning in the context of the camping environment*, M.Sc. Cranfield University

Mendoza, J. A., and Hampson, N. B., 2006. Epidemiology of Severe Carbon Monoxide Poisoning in Children. *Undersea and Hyperbaric Medical Society.* 33 (6), pp. 439-446

Milner, J., Hamilton, I., Shrubsole, C., Das, P., Chalabi, Z., Davies, M., and Wilkinson, P., 2015. What should the ventilation Objectives be for Retrofit Energy Efficiency Interventions of Dwellings? *Building Services Engineering Research and Technology.* I36 (2), pp. 221-229

Moschandreas, D., Relwani, S., Johnson, D., and Billick, I., 1986. Emission rates from Unvented Gas Appliances. *Environment International.* 12, pp. 247-253

Myers, R. A. M., DeFazio, A., and Kelly, M. P., 1998. Chronic Carbon Monoxide Exposure: A Clinical Syndrome Detected by Neuropsychological Tests. *Journal of Clinical Psychology.* 54 (5), pp. 555-567

Naylor, S., Walsh, P. T., and Dowker, K. P., 2013. Survey of the reliability of carbon monoxide alarms deployed in domestic homes and efficacy of use by consumers. *Indoor Air.* 23, pp. 325-331

Nazari, J., Dianat, I., and Stedmon, A., 2010. Unintentional Carbon Monoxide Poisoning in Northwest Iran: a 5-year study. *Journal of Forensic and Legal Medicine.* 17, pp. 388-391

Noa, R., 2016. Disaster Related Mortality Surveillance Training [presentation]. *Centre of Disease Control and Prevention Summit 2016.* Atlanta: CDC

Prockop, L. D., and Chichkova, R. I., 2007. Carbon Monoxide Intoxication: An Updated Review. *Journalm of the Neurological Sciences.* 262, pp. 122-130

Popovic, V. M., Atanasijevic, T. C., Nikolic, S. D., and Micic, J. R., 2009. Concentration of Carbon Monoxide in Carbonized Bodies – Forensic aspects. *Legal Medicine.* pp. 318-320

Ralston, J. D., and Hampson, N. B., 2000. Incidence of Severe Unintentional Carbon Monoxide Poisoning Differs Across Racial/Ethnic Categories. *Public Health Reports.* 115, pp. 46-51

Raub, J. A., Mathieu-Nolf, M., Hampson, N. B., and Thom, S. R., 2000. Carbon Monoxide Poisoning – a Public Health Perspective. *Toxicology.* 145, pp. 1-14

Raw, G. J., Coward, S. K. D., Brown, V. M., and Crump, D. R., 2004. Exposure to Air Pollutants in English Homes. *Journal of Exposure Analysis and Environmental Epidemiology.* 14, pp. 86-94

Risavi, B. L., Wadas, R. J., Thomas, C., and Kupas, D. F., 2012. A Novel Method for Continuous Environmental Surveillance for Carbon Monoxide Exposure to Protect Emergency Medical Service Providers and Patients. *Journal of Emergency Medicine.* 44 (3), pp. 637-640

Roderique, J. D., Josef, C. S., Feldman, M. J., and Spiess, B. D., 2015. A Modern Literatyre Review of Carbon Monoxide Poisoning Theories, Therapies, and Potential Targets for Therapy Advancement. *Toxicology.* 334, pp. 45-58

Ruas, F., Mendonça, M. C., Corte Real, F., Vieira, D. N., and Teixeira, H. M., 2014. Carbon Monoxide Poisoning as a Cause of Death and Differential Diagnosis in the Forensic Practice: A Retrospective study, 2000-2010. *Journal of Forensic and Legal Medicine.* 24, pp. 1-6

Rupert, D. J., Poehlman, J. A., Damon, S. A., and Williams, P. N., 2013. Risk and protective behaviors for residential carbon monoxide poisoning. *Injury Prevention.* 19, pp. 119-123

Satran, D., Henry, C. R., Adkinson, C., Nicholson, C. L., Bracha, Y., and Henry, T. D., 2005. Cardiovascualr Manifestations of Moderate to Severe Carbon Monoxide Poisoning. *Journal of the American College of Cardiology.* 45 (9), pp. 1513-1516

Sharma, S., Gupta, R., Paul, B. S., Puri, S., and Garg, S., 2009. Accidental Carbon Monoxide Poisoning in our Homes. *Indian Journal of Critical Care Medicine.* 13 (3), pp. 169-170

Sharpe, M., 2004. Safe as Houses? Indoor air Pollution and Health. *Journal of Environmental Monitoring.* 6, pp. 46-49

Sharpe, R. A., Thornton, C. R., Nikolaou, V., and Osborne, N. J., 2015. Higher Energy Efficient Homes are Associated with Increase Risk of Doctor Diagnosed Asthma in a UK Subpopulation. *Environmental International.* 75, pp. 234-244

Shrubsole, C., Ridley, I., Biddulph, P., Milner, J., Vardoulakis, S., Ucci, M., Wilkinson, P., Chalabi, Z., and Davies, M., 2012. Indoor pm2.5 Exposure in London's Domestic Stock: Modelling Current and Future Exposures Following Energy Efficient Refurbishment. *Atmospheric Environment.* 62, pp. 336-343

Shrubsole, C., Macmillan, A., Davies, M., and May, N., 2014. 100 Unintended Consequences of Policies to Improve the Energy Efficiency of the UK Housing Stock. *Indoor and Built Environment.* 23 (3), pp. 340-352

Silvers, S. M., and Hampson, N. B., 1995. Carbon Monoxide Poisoning among Recreational Boaters. *The Journal of the American Medical Association.* 274 (20), pp. 1614-1616

Stave, K., 2010. Participatory System Dynamics Modelling for Sustainable Environmental Management: Observations from Four Cases. *Sustainability*. 2, pp. 2762-2784

Tam, C., and Crump, D., 2009. Carbon Monoxide: a Review Focusing on the Public Health Impacts of Exposure from Gas Appliances in the UK. Bedford: Institute of Environment and Health

Tam, C. W., Bevan, R. J., Harrison, P. T. C., Youngs, L. C., and Crump, D., 2011. Public Health Impacts to carbon Monoxide from Gas Appliances in UK Homes – are we Missing Something? *Indoor and Built Environment.* 21, pp. 229-240

The Building Regulations 2010: Combustion Appliances and Fuel Storage Systems. 2010. Approved Document J. London: HM Government

The Gas Safety (Installation and Use) Regulations 1998. 1998. London: HM Government

The Smoke and Carbon Monoxide Alarm (England) Regulation 2015. 2015. SI 2015/1693. London: HMSO

Thomassen, O., Brattebo, G., and Rostrup, M., 2004. Carbon Monoxide Poisoning Whilst

Using a Small Cooking Stove in a Tent. *American Journal of Emergency Medicine.* 22 (3), pp. 204-206

Townsend, C. L., and Maynard, R. L., 2002. Effects on Health of Prolonged Exposure to Low Concentrations of Carbon Monoxide. *Journal of Occupational and Environmental Medicine.* 59, pp. 708-711

Traynor, G. W., Girman, J. R., Apte, M. G., Dillworth, J. F., and White, P. D., 1985. Indoor Air Pollution Due to Emissions from Unvented Gas-Fired Space Heaters. *Journal of the Air Pollution Control Association.* 35, pp. 231-237

Varon, J., Marik, P. E., Fromm, R. E. and Gueler, A., 1999. Carbon Monoxide Poisoning: A Review for Clinicians. *The Journal of Emergency Medicine.* 17 (1), pp. 87-93

Vermesi, I., Restuccia, F., Walker-Ravena, C., Rein, G., 2015. *Carbon Monoxide Diffusion through Porous Walls: A Critical Review of Literature and Incidents*. Massachusetts: Fire Protection Research Foundation

Vreman, H. J., Wong, R. J., Stevenson, D. K., Smialek, J. E., Flowler, D. R., Li, L., Vigrorito, R. D., and Zielek, H. R., 2006. Concentration of Carbon Monoxide (CO) in Postmortem Human Tissues: Effect of Environmental CO Exposure. *Journal of Forensic Sciences.* 51 (5), pp. 1182-1190

Weaver, L. K., and Deru, K., 2007. Carbon Monoxide Poisoning at Motels, Hotels, and Resorts. *American Journal of Preventative Medicine.* 33 (1), pp. 23-27

Wilkinson, P., Smith, K. R., Beevers, S., Tonne, C., and Oreszczyn, T., 2007. Energy, Energy Efficiency, and the Built Environment. *Lancet.* 370, pp. 1175-1187

Wilson, R. C., Saunders, P. J., and Smith, G., 1998. An Epidemiological Study of Acute Carbon Monoxide Poisoning in the West Midlands. *Journal of Occupational and Environmental Medicine.* 55, pp. 723-728

World Health Organisation, 2010. *WHO Guideline for Indoor Air Quality*. Denmark: World Health Organisation

Wright, J., 2002. Chronic and Occult Carbon Monoxide Poisoning: we don’t know what we’re missing. *Emergency Medicine Journal.* 19, pp. 386-390

Yari, M., Fouladi, N., Ahmadi, H., and Najafi, F., 2012. Profile of Acute Carbon Monoxide Poisoning in the West Province of Iran. *Journal of the College of Physicians and Surgeons Pakistan.* 22 (6), pp. 381-384

Yu, C., and Crump, D., 2010. Indoor Environmental Quality – Standards for Protection of Occupants' Safety, Health and Environment. *Indoor and Built Environment.* 19 (5), pp. 499-502

Yu, C. W. F., and Kim, J. T., 2012. *Low-Carbon Housing and Indoor Air Quality*. 6th International Symposium on Sustainable Healthy Buildings, 27 February 2012. Seoul, Korea: SHB2012