Real time carbon monoxide measurements from 270 UK homes.

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ABSTRACT

This paper reports the results of a study carried out in Winter 2004/2005 where a large number of homes were monitored for carbon monoxide (CO) concentrations in the main living room for a period of at least one week. The homes were all owner-occupied; all had at least one of the following gas appliances, cooker, water heater, or gas fire; all home owners were in the low income group, considered vulnerable with the occupants generally over 60 and receiving state benefits of some kind.

Dwellings were selected from the WarmZone pilot study project in East London which targeted households believed to be likely to have old appliances or heating systems. Carbon monoxide concentrations were monitored by the Bartlett using a novel CO monitor based on technology developed by one of the team, Ben Croxford, in a previous study of external CO levels.

Three hundred homes in total were monitored, and valid data was gathered from 270 of these. It was found that of the homes with valid datasets, 50 dwellings (18.0% of the total) had CO concentrations that exceeded World Health Organisation 8-hour average guideline levels for outdoor ambient air (8.6 ppm), of these, 26 (9.4% of the total) exceeded WHO 1 hour levels of 26 ppm, and 10 of these (3.6% of the total) exceeded 30 minute guideline values of 52 ppm.

Reports from qualified gas engineers visiting these “exceedance homes” indicate that old, poorly maintained gas fires and gas cookers were found to be the most common source of high CO emissions. Other exceedances could be explained by poor installation and also by user behaviour (e.g. long periods of use of gas appliances without adequate ventilation). Overall 34% of those visited (13/38 or 5% of the 270 home total) had faulty or replaced gas appliances.

Faulty gas appliances could therefore be a relatively widespread and potentially dangerous source of CO in many UK homes. A rough estimate based on the results of this survey suggests 39,000 homes could have a “problem” gas appliance. Exposure to higher levels of CO depends on the appliance and usage, but in some cases could be of concern based on known adverse health effects of CO. A replacement appliance programme could be expected to lead to health improvement.

INTRODUCTION

This paper presents findings from the monitoring campaign part of a project examining the association between neuropsychological function and chronic exposure to carbon monoxide (CO) in indoor air. Funding was provided by the UK Department of Health and the monitoring campaign was carried out between November 2004 and April 2005. The neuropsychological effects and epidemiological analysis are contained in a final report (unpublished) to the UK Department of Health and will be published as an academic paper shortly.

Data are lacking on the consequences of prolonged (days to months) exposure to low level carbon monoxide (CO). While acute CO poisoning is usually well recognized (producing effects ranging from headache, weakness and nausea to chest pain, seizures, and death), there is evidence that the symptoms of chronic exposure are often unrecognized or misdiagnosed as chronic fatigue syndrome, viral or bacterial pulmonary or gastrointestinal infection, or a psychiatric condition [Dolan et al 1987, Penney 2000, Kirkpatrick 1987]. Measurements of CO in homes and carboxyhaemoglobin (COHb) in blood are often not made in affected individuals, and in consequence the cause of their continuing ill health frequently remains undetermined [Hay, Jaffer, Davis 2000].

It is less clear, however, what effects occur from long-term exposure to much lower (but above normal) indoor concentrations of CO [Klasner et al 1998]. Many of the reported symptoms (physical, cognitive, emotional and visual) appear to be related to the central nervous system, [Penney 2000, Kirkpatrick 1987, Hay et al 2000, Myers et al 1998, Wilson 1996, Choi 1983] but the literature is largely anecdotal and, where formal assessments have been used, there is often imprecision about the levels and chronicity of exposure, about the methods of assessment, and about patient selection [Crawford et al 1990, Lowe-Pensford and Henry 1989, Roos 1994, Meredith and Vale 1988, Samuels et al 1992]. Nonetheless, there have been repeated indications of persistent neurological sequelae that, pathologically, may reflect damage to both gray and white matter of the nervous system [Taylor 1992]. Neurological signs may be absent but impairment of attention, short-term memory, and executive functioning have been reported following detailed neuropsychological testing [Lader and Morris 2001]. The experience of some members of the project team from the medical toxicology clinic at Guy’s Hospital is that subjective complaint of difficulties in cognitive functioning is a frequent presenting feature of people with chronic low level CO exposure. Some of these people have been found by psychometric tests to have impaired cognitive functioning, and many also complain of emotional and physical difficulties.

Unfortunately, a major problem in interpreting evidence about clinical effects in CO-exposure is the bias that may arise from the self-selection of patients with apparent symptoms, and the potential for subjective modification of symptoms once a diagnostic label of CO-toxicity is applied [Gupta and Horne 2001, Gupta et al 1997]. For this reason, it is important that evidence of neuropsychological impairment is based on epidemiological study of unselected populations - i.e. of representative groups of people from the community with no prior awareness of their own CO exposure.

Indoor concentrations of carbon monoxide are a function of outdoor concentrations, indoor sources, ventilation and air mixing between and within rooms [IEH 1998]. In residences without sources, average indoor carbon monoxide concentrations are approximately equal to average outdoor levels [WHO 1999]. The average level inside the home is usually just a few parts per million (ppm), typical external values in rural areas would be around 1 ppm and in cities might reach 3 or 4 ppm on still days in busy streets.

A study of 14 homes in the UK found a mean unadjusted value of ambient CO in the kitchen of 3.5 mg/m3 (3.1 ppm) [IEH 1998]. A study of indoor pollutants in 876 English homes using colourimetric diffusion tubes found a mean of 1 ppm (1.1mg/m^3) for homes using gas cookers in winter, (assumed to be around 100 homes, subgroup numbers not given in the paper) [Raw et al 2004]. Passive cigarette smoke was found to increase a non-smoker's exposure by an average of about 1.7 mg/m3 (1.5 ppm) and use of a gas cooking range at home by about 2.9 mg/m3 (2.5 ppm) [WHO 1999]. Our own evidence from studies of residential dwellings in London suggests behaviour within the home rather than ventilation type determines CO concentration in kitchens [Oreszczyn et al 1998].

Evidence suggests that a surprisingly large proportion of homes have CO levels appreciably above normal. In a survey of 1820 randomly selected homes in the US, 17% had air concentrations of CO above 10 ppm [Schaplowsky et al 1974]. While this level seems high, in the UK the use of gas appliances is more common and homes tend to be older and often contain old appliances.

A pilot monitoring campaign for the current project found elevated CO levels in 56 homes. The homes belonged to low income families, or pensioners on benefits and could be considered vulnerable. Nearly 25% (13/56) of homes were found to have exposures above WHO guidelines (see Table 1) and of these 14% (8/56) were found to have problem appliances emitting high levels of CO [Croxford et al 2005].

In homes with faulty or unvented combustion appliances, ambient levels of CO can exceed 110 mg/m3 (100 ppm), leading to carboxyhaemoglobin levels in excess of 10% with continued exposure [WHO 1999, Raub et al 2000]. At these very high levels, numerous studies suggest that clinical impairment of cognitive and motor function occur [Lambert 1996]. (The physiological norm for carboxyhaemoglobin level is around 0.3 – 0.7% in non-smokers and 4% in smokers [WHO 1999]).

BACKGROUND INFORMATION

Currently there are no indoor regulations for carbon monoxide (CO) concentrations; one of the reasons for this is that levels are strongly affected by smoking, and occupant behaviour. However the World Health Organisation has published guideline levels for ambient CO concentrations and these are shown below in Table 1. Further details about CO can be found in WHO (1999).

Table 1: World Health Organisation Guideline Limits For Carbon Monoxide Exposure. (WHO 1999).

Carbon monoxide concentration (mg/m3)	Carbon monoxide concentration (ppm)	Duration
100	87	for 15 min
60	52	for 30 min
30	26	for 1 h
10	8.6	for 8 h

METHODS

The methods section describes how the monitoring portion of the study was carried out and is split into two parts, describing the sampling strategy for the homes and the monitoring itself.

Sampling Strategy

Homes eligible for new heating systems under a government programme to reduce fuel poverty were considered to be likely to have old, poorly maintained gas appliances - and hence be at risk of high CO levels. It was expected that targeting these homes would lead to us finding a substantial number of households with both high and low CO exposure, from which we could gain much needed and unbiased evidence about the relationship between CO exposure and neuropsychological function.

The monitoring campaign is an addition to an ongoing population survey of dwellings in East London aimed at reducing fuel poverty, [WarmZones 2005]. Homeowners were contacted and surveyed by a specially trained team of surveyors. Each homeowner was interviewed to determine eligibility for income support or grants; each home was also surveyed to determine the need for energy efficiency measures. The WarmZone team help the homeowner receive measures that may include the replacement of internal boilers/central heating systems.

Individual homes were selected for the study if they comply with certain criteria:

- homes must be privately owned or privately rented
- homes must have gas heating and gas appliances (gas cooker, gas fire, gas boiler etc)
- occupiers must have lived in the same home for at least 5 years, preferably longer
- homes should have had no replacement heating system during that time.
- residents must speak English as a first language
- residents must be prepared to undergo a 2 hour interview in their homes (a small payment in the form of a gift voucher will be made to thank participants for their time).
- Preferably households should be non-smoking

Three hundred homes were selected from the housing stock of 5 East London boroughs. The selection process was not completely random as it was influenced by the individual surveyor and the agreement of the householder to participate. Full home surveys and a limited health questionnaire were carried out in all of the selected homes.

In general the homes were occupied by low-income families, often with old and poorly maintained heating systems, and hence were expected to have a high frequency of elevated CO concentrations. The study proposal was submitted to the ethics committee at Guy’s Hospital, and obtained approval.

Monitoring Strategy

A continuous CO monitor was placed in each of the selected dwellings. At the end of the measurement period, (minimum period 1 week) monitors were collected, the data was downloaded and the monitor recycled within the project. Measurements of CO and temperature were made every minute and the averages were stored every 15 minutes for the entire monitoring period.

The surveyors were instructed to install the CO monitor in the main living room of the dwelling. The exact location depended on the layout of the dwelling, but all were located away from any direct CO source, (cooker or gas heater), and also any source of cleaner air, such as doorways, windows, or ventilation systems and away from direct sunlight. The height was specified as being as close as possible to the head height of a seated adult.

The monitor was a small, low cost, monitor called the ICOM from Learian Environmental, [Croxford, Fairbrother 2005]. This monitor has achieved a very high level of accuracy, +/- 5%, resolution 0.1 ppm, for levels between 0.1 ppm and 50 ppm. It is based on technology used in the commercial, ambient CO monitor, the StreetBox also produced by Learian Environmental. The prototype for the StreetBox monitor was originally developed at UCL by one of the team [Croxford et al 1996]. A similar method was used in the “Carbon monoxide concentration and ventilation strategies” project that investigated the effects of ventilation on carbon monoxide levels in 45 homes with gas cookers [Oreszczyn et al 1998].

After the monitor was retrieved from the home, the data was downloaded, and the raw data file was passed through a proprietary software package, called Minilogger, to calibrate and quality check the measurements. A detailed spreadsheet for each home was produced along with a general spreadsheet containing all summary statistics for each home.

The WHO guidelines in Table 1 formed the action levels for this study; if homes were found to be above the lowest level then arrangements were made for a gas engineer to visit and perform an appliance check on all appliances. If the highest level was breached then a phone call to notify the householder was made to warn the householder of possible dangerous levels of CO. The Council for Gas Detection and Environmental Monitoring (CoGDEM) provided funding for a gas engineer to visit all exceedance homes and to check all gas appliances.

Discussion of Errors

In a monitoring campaign of this nature there are many factors that can affect the measured results. In this project two sources of error are considered the most important. The monitors themselves have an error of approximately +/-5%, but the second source is much large and is associated with the concept that measured concentration in the living room is a proxy for CO exposure. The monitor was placed by the surveyor in a convenient place in the main living room. The CO measurements made are thus specific to the precise location within the room, and depend on the room layout, the home layout and air movement within the room. Also, different people in the home will spend different times in different rooms, if the main source of CO was in the kitchen then the average measured in the living room may not be a good proxy of exposure for someone who spends most their time in the kitchen. As we were measuring in winter we expected that all windows would be closed for most of the time, allowing better mixing of the indoor air, making the CO measurements more representative of the home. Considering this, three main variables were recommended to be used for later analysis with respect to health: average carbon monoxide; 95th percentile carbon monoxide; and a variable recording how many suspect or problem gas appliances are in the home. This last variable is based on gas engineer reports; if for example one burner out of 4 and the grill for one cooker was found to be emitting dangerous levels of CO then this would count as 2.

A conservative estimate of total error for the first two variables including the effects of both sources of error mentioned above, might be +/-50%, the last variable has an estimated false negative error in the region of 1 in 50 and a false positive error of around 1 in 25.

RESULTS

The results from the monitoring programme are summarized in tables and figures in this section.

Table 2 shows the overall summary results for all homes monitored. The monitoring period ranged from about 1 week to a maximum of 32 days. Eight homes with much less than a week of data were excluded from the analyses leaving a total of 270 homes with sufficient data to be included. Twenty two homes had technical problems with the monitors including problems with batteries and accidental switching off. It can be seen that a high proportion of homes monitored (50/270 or 18%) had CO levels that exceeded WHO guidelines for CO in ambient air. A total of 13 homes (4.8 %) were found to have at least one appliance that was emitting high enough levels of concern for a gas engineer to warn householders not to use it.

Also shown are the mean for each sub group and the standard deviation for each sub group.

Table 2: Overall Summary Table Of CO Measurements

	Number of monitored homes	Percentage of total valid measurements	Overall mean (ppm)	Std. Dev. (ppm)
Total monitors placed	300			
Total monitors with data	278			
Total monitors with sufficient data	270	100.0	1.7	1.6
Number of homes exceeding WHO 8hr guideline (8.6 ppm)	50	18.5	4.0	2.6
Number of homes exceeding 1hr WHO guideline (26 ppm)	26	9.6	4.8	3.2
Number of homes exceeding WHO 30 minute guideline (52 ppm)	10	3.7	6.3	4.1
Number of homes with at least 1 “problem appliance”	13	4.8	1.8	1.2

Figure 1 shows the trace of carbon monoxide concentrations over time for a home with typical exposure. The peaks seen occur either around midday or evening and thus correspond to cooking, overall the concentrations remain below 10ppm for the duration of the monitoring period. Figure 2 is a home with a problem gas appliance. Here the concentrations exceed 80 ppm. To see the pattern of carbon monoxide over the course of a day we plot the concentration versus hour of day for all data. Figure 3 has the same data as figure 2 and clearly shows how peaks regularly occur around 10:00, 16:00 and after 20:00, low levels are seen during the night and very early morning. This suggests that peaks may be related to meal times and suggests a possible source as being a gas cooker. Peaks above 80 ppm occurred and exceeded the WHO 30 minute limit of 50 ppm. The gas engineer reported no access possible.

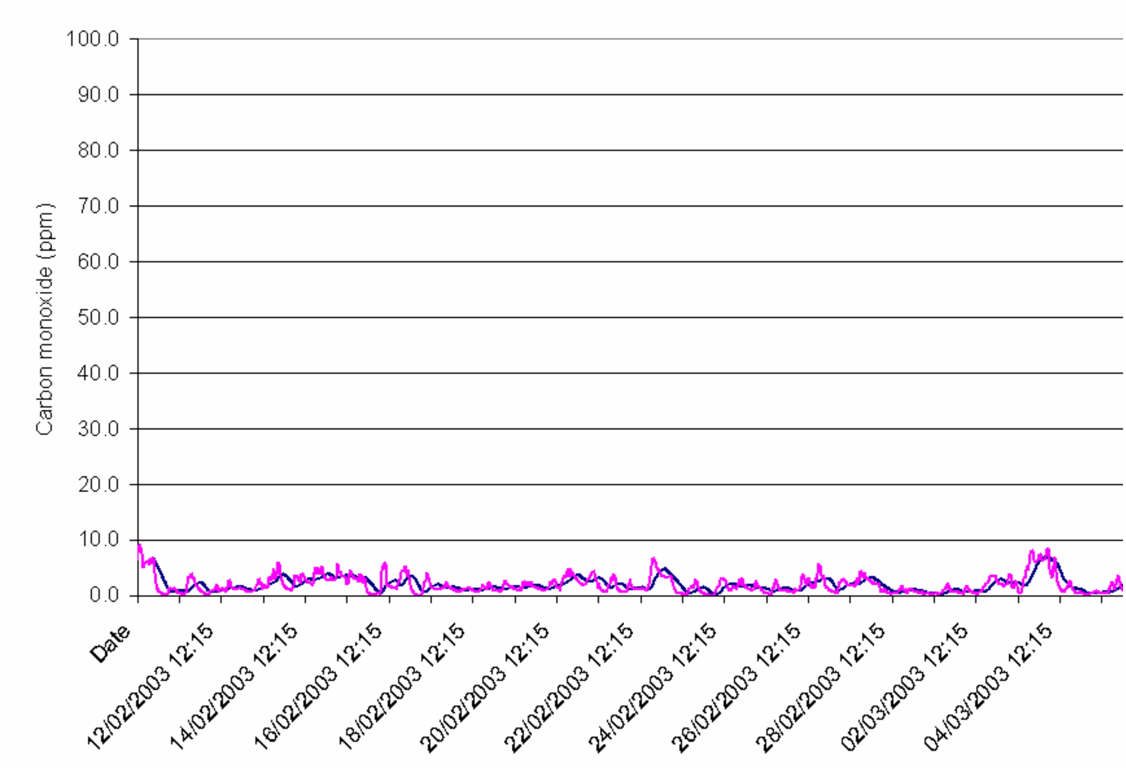

Figure 1: Carbon monoxide measurements from a typical home (E10_5DS_172), (the lighter line is the 15 minute average data, the darker smoothed line is the 8 hour moving average value) .

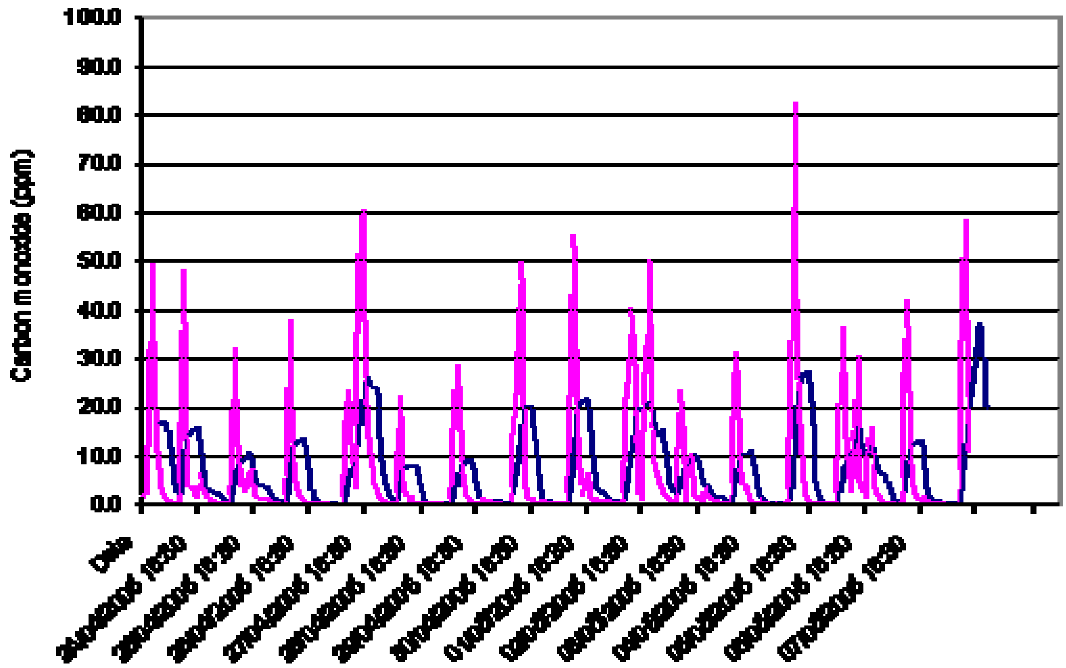

Figure 2: Carbon monoxide measurements from a home with a problem gas appliance (E11_3LY_274).

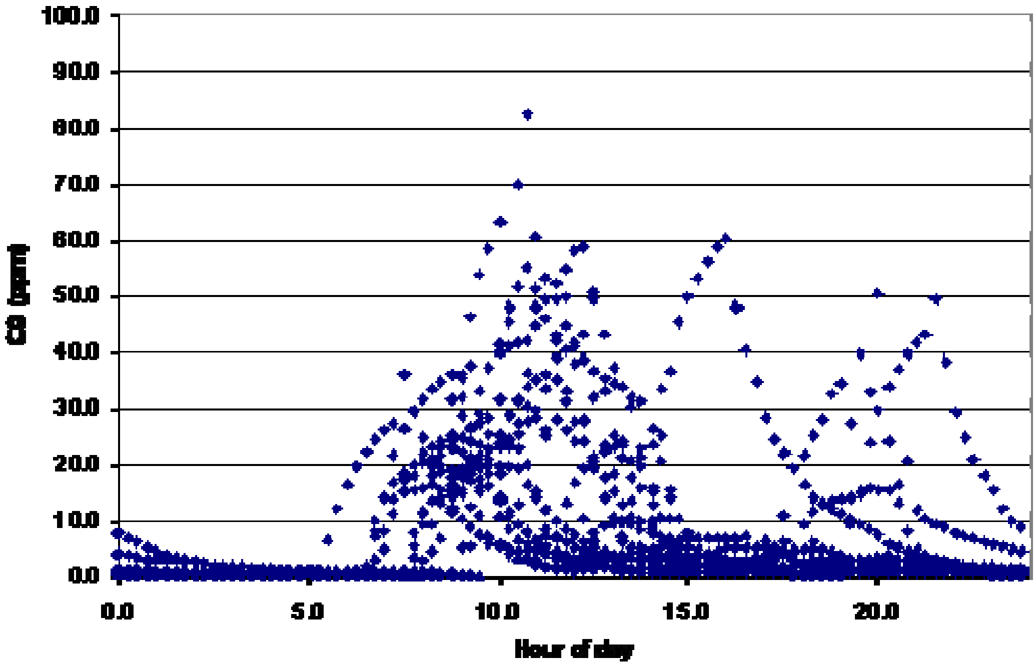

Figure 3: Time profile of CO concentrations for home shown in figure 2 (E11_3LY_274) all data for a period of about 10 days is presented by hour of the day, the highest peak occurs at hour 10.75 corresponding to 10:45am.

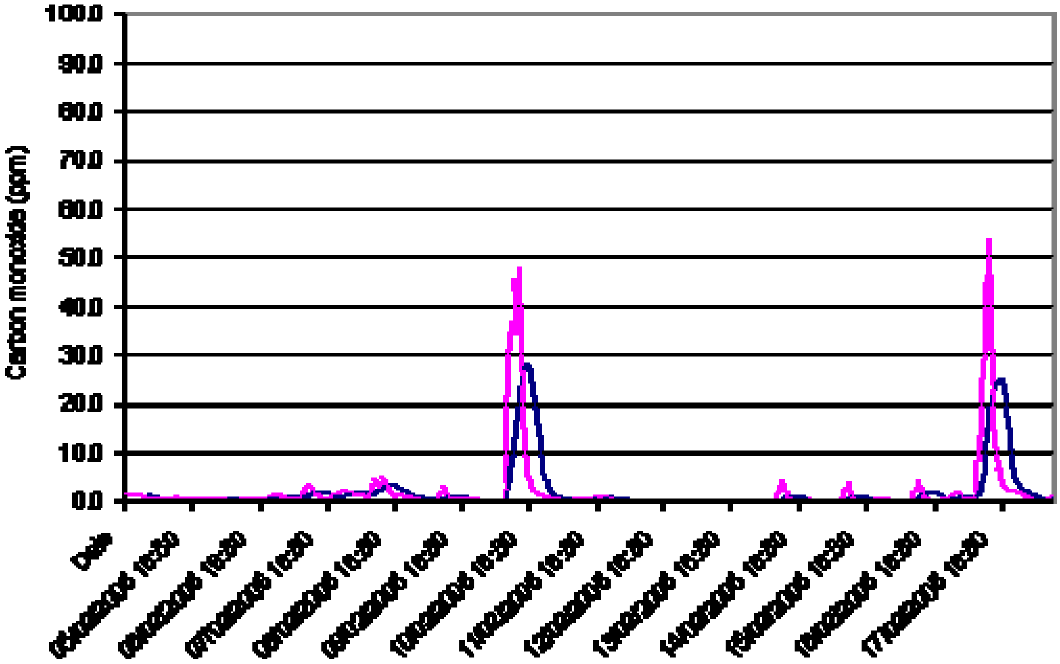

Figure 4: Carbon monoxide measurements from a home with exceedances only on Saturdays (N16_6NP_137).

Figure 4 shows a home with regular weekly exceedances, several homes were found with this pattern of low levels for most of the week, with one day where exceedances occurred. This was sometimes but not always associated with religious observances; a gas cooker was left on all day on the Sabbath but no corresponding ventilation was in operation so CO concentrations built up.

The graph in figure 5 is included to explore the predictability of the exceedance of the WHO 8 hour guideline figure by plotting hours of exceedance of the WHO 8-hour guideline against mean, the maximum and the 95th percentile CO measurements. The average can be seen to have the best correlation coefficient or to be the best predictor of WHO 8 hour exceedances. From the correlation equation if the average CO level over the period was less than 2.1 ppm then there were expected to be no exceedances.

No significant difference was found between mean CO concentrations of smokers and non-smokers, unfortunately not all cases had smoking information, (non-smokers 58, mean = 1.8 ppm, smokers n=13, mean = 2.3 ppm, t-test gives p=0.22).

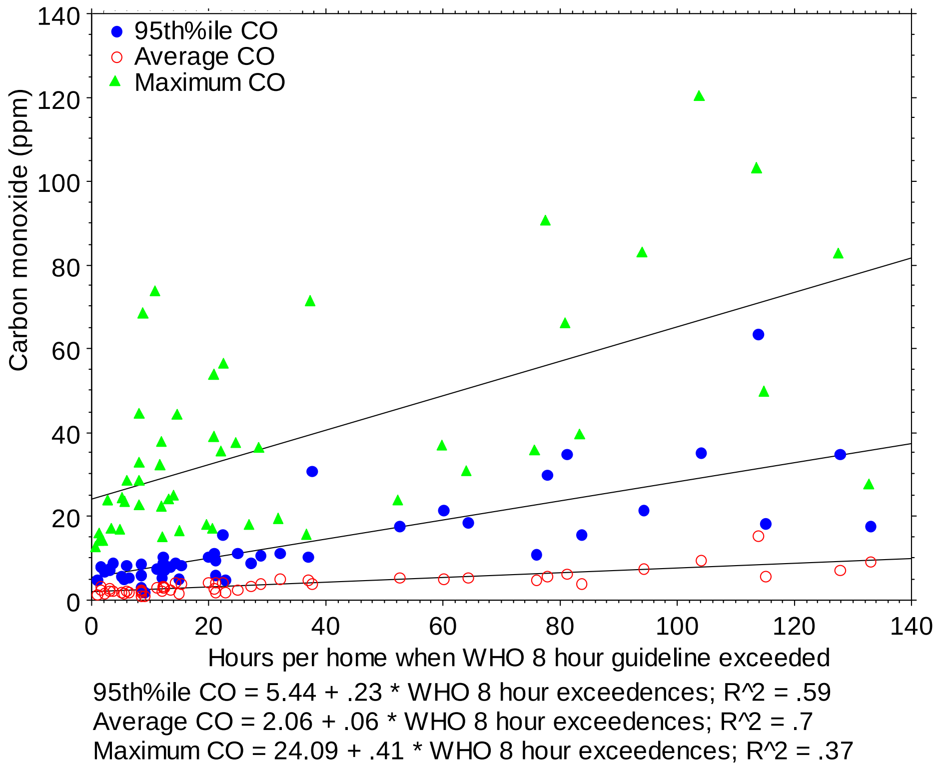

Figure 5: Comparison of hours of WHO 8hr guideline exceedance with maximum, mean and 95th percentile values.

A gas engineer was instructed to test all gas appliances, gas cookers, grills, ovens hobs, gas fires, gas boilers in each home selected according to the relevant British Standard [BS7967]. 77 homes were selected for visits, (these included the 50 exceedance homes and 27 of the next highest exposure homes), in 21 no access was possible, 2 refused entry, leaving a total of 54 homes visited.

Of the 10 highest exceedance cases, 9 were visited, and 7 had problem appliances. For the remaining 67 cases, 20 were not visited; at least one problem was found with gas appliances in 18 of 47 remaining cases. (A problem might be one burner on a gas hob emitting high concentrations of CO). Of those homes (50) who had at least one exceedance of the 8 hour CO guideline, gas engineers managed to visit 38, of these 13 or 34% were found to have faulty (or replaced) gas appliances.

KEY PROBLEMS / ACHIEVEMENTS

The team considered the monitoring campaign to be quite successful in terms of numbers of homes monitored, some reasons for this success are worth identifying for future projects and are listed below:

- The equipment had been tried and tested in a pilot project, the processes and methodology of use are now clearly documented and it is easy to train others
- The survey site was geographically relatively close to the university (10km to the East) allowing for immediate problem solving if necessary
- Excellent project management and control of surveyors by WarmZone personnel

Some aspects that could have been improved or could be considered in future campaigns:

- the logistics of monitoring in people's homes is always subject to homeowners' permissions, delays can occur in contacting both for placing and retrieval of monitors, if people are out then nothing can be done!
- Several factors can cause bottlenecks in monitoring throughput; these include numbers of monitors, numbers of rechargers, number of downloading cables, availability of laptop for downloading, illness of key personnel, and throughput of homes to monitor, seasonal factors; and holidays (eg Christmas)

CONCLUSIONS

The main conclusion to draw from this monitoring programme is that a large proportion of homes (18% of our sample) exceed one or more of the WHO guideline values for carbon monoxide, (table 1). Upon further investigation the cause of these exceedances was identified as often being an old and poorly maintained gas appliance, generally either the cooker or a gas fire.

Of the exceedances it is clear that there are different patterns of carbon monoxide concentrations found in different homes, in each home each pattern depends on many factors;

- where the CO comes from (source),
- how effectively it is removed by ventilation,
- the condition of any gas fired appliances in the home,
- the way these appliances are used,
- and the type of ventilation present in the home.

The main danger identified from the monitoring is that there may be a significant number of homes with dangerous gas appliances. Nearly 5 % of the total sample was found to have at least one element of at least one gas appliance that could be considered dangerous by the visiting gas engineer. The exposure to the occupants from these appliances depends strongly on how they are used. However if an appliance is found to emit high levels of CO then the risk is present to the occupant. In this study the occupants of all of these homes were often elderly and vulnerable people.

The WarmZone program aims to find and help vulnerable homes that are in "fuel poverty" [for current definition see DTI 2006]. The measures that can be installed under this programme include new central heating systems, and draught proofing to improve ventilation heat loss. However neither WarmZone, nor the larger national scale Warm Front Scheme [DEFRA 2006], includes provisions to replace cookers or remove old room heaters. In theory CO concentrations could increase after fuel poverty reduction measures have been installed due to reduced air infiltration whilst keeping old inefficient gas appliances. Currently in the UK there is no program of gas appliance replacement or grants to help families with little spare money that are at risk from CO exposure. One occupant when asked how old her gas cooker was, replied that it had been in her home for 25 years and it was second hand when she got it.

It might be expected that in the whole UK housing stock, the prevalence of high carbon monoxide concentrations would be lower than found in this survey, however, as mentioned in the introduction; other studies have found a similar prevalence of exceedances and similar mean concentrations of carbon monoxide. With 1 million, fuel poor and vulnerable homes in the UK [DEFRA_2 2006], and the percentage of homes using gas at 83% [DTI_2 2005], a conservative estimate (using 4.8% from Table 1) is that at least 39,000 homes will have appliances that have a considerable risk of exposing occupants to high CO levels.

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KEYWORDS
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