Real time carbon monoxide measurements from 56 UK homes

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ABSTRACT

This paper reports results from the monitoring part of a recent UK Department of Health funded project investigating carbon monoxide (CO) levels in homes during the winter of 2002/2003. In all, 56 homes were monitored for carbon monoxide in 3 cities across the UK.

The homes were selected as part of the UK government Warm Front evaluation programme (aimed at reducing fuel poverty) and might be expected to have a higher incidence of problem gas appliances emitting higher than average amounts of CO than the general population. However the ventilation rate of these homes might also be expected to be higher.

Measurements of CO were taken at 15-minute intervals in a representative location in the main living area of each home. Thirteen or 23% of the homes were found to exceed the WHO guideline values for ambient CO concentrations.

In each home that exceeded the guidelines an assessment of source concentration of each appliance was made by an expert gas engineer, it was found that old, poor quality gas appliances caused a large proportion of exceedances seen.

INDEX TERMS

Carbon monoxide, personal exposure, living room, gas appliance.

INTRODUCTION

In the UK it is commonplace for homes to have gas as the main fuel source, for heating, hot water and cooking. The UK Building Regulations specifies ventilation rates and installation requirements for gas-fired appliances used within the home. Some appliances such as boilers must have balanced flues, this ensures that the appliance has sufficient fresh air to burn the fuel properly and also is not dependent, and does not affect ventilation within the home. Un-flued appliances such as gas cookers are permitted but sufficient ventilation must be provided in accordance with the regulations.

If insufficient ventilation is provided, gas appliances can generate high levels of the dangerous gas, carbon monoxide (CO). Within the UK housing stock a number of factors can contribute to the CO concentrations seen;

- a large proportion of the current housing stock was built before the introduction of building regulations

- changes within individual homes can act to alter the original specified ventilation regime.
- gas appliances may not be maintained properly or may have been installed badly.
- Behaviour and preferences of home owners as to how they use their appliances, for example using the oven to heat the kitchen can lead to very different CO concentrations in identical homes.

Carbon monoxide (CO) is a colourless, odourless and tasteless, poisonous gas generally occurring from the incomplete combustion of fossil fuels. The molecular weight and the density of CO, 28 and 1.25 kg/m3 respectively, are similar to those of air, 29 and 1.29kg/m3. In general CO behaves very similarly to the air around it, but at high concentrations >1000ppm it can kill and at lower concentrations can cause headaches and nausea, a large part of its danger is that it we can't see it, smell it or taste it [WHO 1999].

This paper reports on a project, Neuropsychological Effects of Low Level Exposure to Indoor Carbon Monoxide, led by the Medical Toxicology Unit at Guys and St Thomas's hospital, this aimed to monitor a large number of homes to find if individuals with exposure to relatively high levels of carbon monoxide had measurable differences in neuropsychological function compared to people with low exposure. High exposure here refers to levels of carbon monoxide (CO) levels above World Health Organisation (WHO) guidelines. Outdoor guideline standards are used for the indoor values, as there are no specific guidelines for indoor air quality. In the case of CO these guidelines are based on the percentage of carboxyhaemoglobin (COHb) in the blood (WHO 1999).

The adverse health effects associated with exposure to various concentrations of CO are related to the concentration of COHb in the blood. Carbon monoxide binds to haemoglobin much more readily than oxygen, by a factor of 200-300; in this way it reduces the blood's capacity to transport oxygen. The factors determining the level of COHb in blood are considered to be the "amount of inspired CO, the minute alveolar ventilation at rest and during exercise, blood volume, barometric pressure, diffusion capability of the lungs, and endogenous CO supply". Health symptoms caused as a result of CO exposure will in general disappear once either the source, or the person affected by the source is moved. [WHO 1999, Fierro et al 2001].

The project was designed to select homes with people who may have been exposed unknowingly to elevated levels of CO and to test their neuropsychological function compared to people exposed to "normal" levels of CO. Too few homes participated to allow the neuropsychological part of the project to go ahead, this paper reports on the monitoring section of the project.

RESEARCH METHODS

To select and access the homes it was necessary to use another research project, the Health Impact Evaluation of Warm Front programme managed by the Energy Saving Trust (EST 2005). All homes monitored were therefore those that fulfilled a number of criteria, they had households that were in receipt of income support, either over 60 years old or single parent families and were eligible to receive central heating systems under the Warm Front programme. All homes could be therefore classed as being in the poorest section of society and have vulnerable occupants.

The datalogger was designed specifically for this project; they were to be deployed by building surveyors and needed to be accurate and as simple as possible to operate. The solution to this was a simple on/off switch; the datalogger was configured to self-start and record data from the time it was switched on to the moment it was downloaded. A further consideration was occupant feedback, this logger has no lights and makes no sound, as such, no real time information on CO concentrations is given to the user. This was an important consideration, as it was thought that if the occupant thought that they were exposed to high CO levels it was possible this would affect the result of their neuro-psychological testing.

The loggers are small self-contained battery powered devices and use an electrochemical sensor to detect CO. The monitors have an error of +/- 5% at levels above 4ppm or +/- 0.2ppm at levels below this. The loggers monitor CO concentrations every minute and are fixed to output fifteen minute average readings for CO [Croxford and Fairbrother 2004].

The building surveyors were trained to select monitoring positions in the homes, this consisted of following a set of criteria. The aim of the monitoring was to measure occupants' exposure to carbon monoxide, bearing this in mind the ideal monitoring position was considered to be head height of a seated individual in a representative position in the main living area of the dwelling. The surveyors were also asked to make sure that the logger was as far from both sources of CO and draughts as possible and also out of direct sunlight. Most importantly they also had to ensure that the logging position was acceptable to the occupants. It was thus important that the logger was as small as possible and as unobtrusive as possible. When the loggers were placed the surveyors also asked a question about occupant smoking habits, printed on the back of the loggers, and entered the answer on the label of the logger.

At the end of the monitoring period the loggers were returned by post to Croxford at UCL for downloading, recharging and preparing for redeployment. The data after downloading was subjected to quality control. After this process if the concentrations were found to exceed the WHO guideline levels for CO the expert gas engineer Harry Rogers was informed by email of the address, phone number and CO concentrations. Mr Rogers then arranged to visit the home, make a survey of all appliances and report back to Croxford at UCL.

RESULTS

The results from the monitoring programme, including relevant information from the appliance survey and smoking status, are summarized in tables and figures in this section.

Table 1 shows the overall figures for all homes monitored, the monitoring period ranged from about 1 week for 4 homes, about 2 weeks for 2 homes and the remaining 50 homes all had between 3 and 5 weeks of monitored data. A typical home with low levels of CO present, consistent with good ventilation, correctly functioning appliances and a low background level of CO would have background levels of 1-3 ppm CO with occasional peaks up to 10 ppm. Figure 1 shows results from a home that was found to have a malfunctioning gas fire.

On average homes with more than 40 cigarettes smoked per day had higher mean CO levels than those homes with less cigarettes smoked per day, however there were no statistically significant differences found due to the low numbers of homes with heavy smokers. Twenty of the 56 homes were found to have smokers present, (36%), this is consistent with a national smoking prevalence of about 25% of adults [ONS 2002].

Table 1: Summary of CO monitoring programme.

	Number of homes	Mean CO level for group (ppm)	Std. Dev. (ppm)	Minimum (of mean 15 min readings) (ppm)	Maximum (of mean 15 min readings) (ppm)
Total Homes Monitored	56	1.9	1.3	.4	6.9
Homes that exceeded 8 hour WHO guideline	13	3.6	1.5	1.8	6.9
Homes that exceeded 1 hour WHO guideline	6	4.2	1.7	2	6.9
Homes that exceeded 30minute WHO guideline	3	5.5	1.3	4.6	6.9

It was found that the 95th percentile of CO readings is fairly closely related to the overall mean (r2=0.89) but the maximum value recorded has much less association with the overall mean (r2=0.62). A similar pattern was found with temperature measurements, the 95th percentile of air temperature measurements was found to be associated with mean air temperature, (r2=0.74) but the maximum temperature was only fairly closely related to mean temperature (r2=0.57). No relationship was found between temperature and carbon monoxide levels even when considering mean, 95th percentile, and maximum measurements. No significant difference was seen in mean CO concentrations between the three city areas, Manchester (16 cases, mean CO = 2.0 ppm), Birmingham (26 cases, mean CO = 1.9 ppm) and Liverpool (12 cases, mean CO = 1.8 ppm).

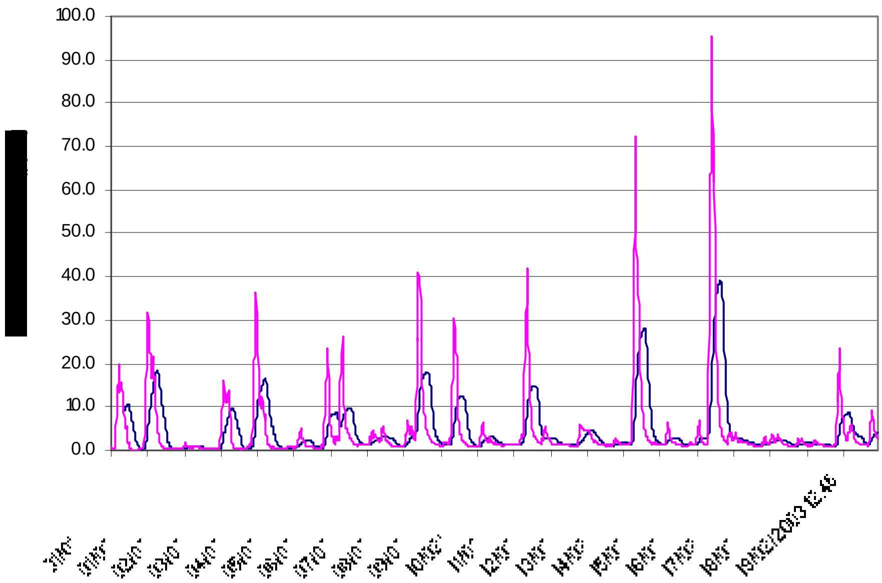

Figure 1: Carbon monoxide measurements from a home with a problem gas fire (House number 447374). The lighter line is the 15-minute average data, the darker smoothed line is the 8 hour moving average value.

Table 2: Exceedance cases source analysis

Source	**Frequency**
Gas grill	3
Gas fire	3
Gas grill from flat below	1
Incorrect installation of gas fire	1
Joss / incense sticks	1
Letter or telephone contact, (not visited by engineer)	4
Total exceedance cases	13
Total overall homes monitored	56

A high proportion of homes monitored (13/56 or 23%) had CO levels that exceeded the WHO guidelines. The gas engineer, Harry Rogers, visited most of these cases; he found the most frequent source to be poorly maintained, old or faulty gas appliances. Table 2 presents source data compiled from his reports. The numbers are too low to draw statistically significant conclusions from, but indicate that more than 10% of homes in this sector of the population have gas appliances that could be dangerous. Two appliances were condemned and disconnected from the supply as they were found to produce CO concentrations of >1000ppm in the vicinity that a user would be exposed to (breathing this concentration of CO can kill in under an hour). For one exceedance the most likely source was identified as burning of joss or incense sticks [Croxford, Kynigou 2004].

DISCUSSION

There are many instances in the literature concerning carbon monoxide poisonings and adverse health effects. But this study is one of the first that monitors home environments for several weeks and then investigates the results in such detail. Results show that 13 of the 56 dwellings monitored (23%) had carbon monoxide (CO) concentrations that exceeded World Health Organisation guideline values. Of these 13 had 8 hour moving average concentrations of over 8.6 ppm (10mg/m3), 6 exceeded WHO 1 hour levels of 26 ppm(30mg/m3) and 3 of these exceeded 30-minute guideline values of 52 ppm (60mg/m3)

When considering the results presented in this paper it is important to note that when carrying out monitoring campaigns it is almost always impossible to monitor in the perfect monitoring position due to a variety of logistical reasons and the precise location of the monitor will affect the concentration of the monitored variable. The ICOM logger used was designed to monitor accurately, and unobtrusively the concentrations of CO in people’s homes. However, despite the best efforts of the researchers and surveyors used in the project, the logger position may not have been representative of the homeowner exposure, and also the presence of the logger may have affected the behaviour of the occupants.

It is well known that the pattern of CO concentration in an individual home differs according to the CO emission rate of an appliance, the ventilation rate of the home and the behaviour of the occupants. During this project we collected no direct data on ventilation rate or behaviour but we have gained an insight into a possible problem area in homes, that of poorly maintained gas appliances that emit high levels of CO. The CO emission rate depends on which appliance is burning gas and how efficient that particular appliance is; if the burner is dirty for example or poorly installed it will burn much less efficiently.

CONCLUSIONS AND IMPLICATIONS

Personal exposure to CO depends on how much CO one breathes in and how effective the body is at removing CO from the blood stream. The WHO guideline values for CO set the standards in terms of concentration, consequently a strong source in a small volume will lead to a high concentration.

Perhaps the most worrying aspect of this research is that such a high proportion of homes were found to exceed WHO guideline levels. These homes were all selected from homes in the low income sector of the population and it was expected that we would find some poorly maintained appliances, but these homes also might be expected to have a higher ventilation rate than the typical UK home which would act to reduce concentrations of CO.

Further monitoring work is being carried out over the winter of 2004/2005, with the aim of identifying the health effects of these elevated CO levels.

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