Carbon Monoxide Measurements in Homes

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ABSTRACT

Carbon monoxide is one of the contaminants in homes that engenders the most concern. Programs that evaluate homes spend substantial effort evaluating carbon monoxide. Furnaces, boilers, water heaters, and ovens/ranges are common sources of carbon monoxide in the indoor environment. This paper presents results of carbon monoxide measurements from two studies that looked at homes that underwent energy efficiency upgrades as part of the U.S. Department of Energy's low-income Weatherization Assistance Program (WAP). In the first study, carbon monoxide was measured in the flues of furnaces, boilers, and water heaters, in the outlets of ovens/ranges, and in the indoor ambient air. Measurements in the appliance combustion gases was done once while at the site, and indoor air measurements were done using dataloggers recording for about one week. In the second study the focus was only on measured indoor ambient air, also with measurements using dataloggers for about a week. The results show that most appliances have carbon monoxide levels in flue gases within allowable standards, though some have elevated production. Regarding indoor ambient air, very few homes have persistent levels of carbon monoxide of 5 ppm or higher. However, elevated peak levels above 9 ppm are much more common. These results show that elevated indoor ambient carbon monoxide is a highly episodic contaminant, and therefore not well addressed by whole-home ventilation. Further, the data suggest that it is the cooking appliances that are most subject to producing short-term elevations of carbon monoxide. This paper also includes a comparison of carbon monoxide before and after retrofits.

INTRODUCTION

Carbon monoxide (CO) is a colorless, odorless, and poisonous gas. Its toxicity stems from the fact that it readily binds with hemoglobin in blood, which reduces the amount of oxygen available to organs. Carbon monoxide in buildings is most commonly associated with incomplete combustion. Potential sources including unvented combustion appliances (including space heaters and kitchen ranges), vented combustion appliances (furnaces, boilers, water heaters, free-standing stoves, fireplaces etc.) under conditions in which some of the combustion products "spill" (are released inside the building), gasoline engines (including automobiles started or operated in attached garages, and engine-generator sets operated indoors), charcoal grills operated indoors, and smoking.

It is common in residential energy efficiency programs to measure carbon monoxide (CO) in fuel-fired appliances and in indoor air and to take extensive precautions to prevent CO from getting into the home. Measurements in appliances are typically done using combustion analyzers, while indoor air measurements are made using personal CO monitors. The personal CO monitors are primarily for worker protection, but in the event that

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high levels of CO are found this information is communicated to the resident.

Two recent studies, which generally investigated multiple contaminants in the context of energy-focused retrofits, included evaluations of CO in treatment homes. The first study was a part of a larger evaluation of the U.S. Department of Energy's Weatherization Assistance Program (WAP) (Pigg et al. 2014). This study included one-time CO measurements in furnaces, water heaters, rangetop burners, and ovens, as well as week-long datalogging of indoor air CO levels. The second study was funded by the U.S. Department of Housing and Urban Development (HUD) (Francisco et al. 2015). This study did not include measurement of appliance CO levels but did include datalogging of CO levels in indoor air over about a week-long period.

METHODS

In the WAP study, a field technician used a combustion analyzer to measure CO levels in the flues of fuel-fired furnaces and water heaters, above each gas rangetop burner, and in the vent of each gas oven. These measurements were taken after approximately 5 minutes of appliance operation to avoid short-term transient levels as the appliance heated up. Data were compared to industry standard appliance CO thresholds.

In both studies a datalogger was placed in a central location in the home for about a week. Sampling intervals ranged from 1 minute to 5 minutes. The data were reviewed for average CO levels, peak CO levels, and for indications of the cause of CO elevations in the indoor air. Measurements of CO were not taken in the garage.

RESULTS

Appliance CO Levels

There were 111 furnaces and 200 water heaters that were tested in treatment homes as a part of the WAP study. At the time of the study, the comparison levels for flue gases were 400 parts per million (ppm) in furnaces and 100 ppm in water heaters. For furnaces, 38% were natural-draft, 39% were induced-draft, and 23% were power-vented before weatherization. This distinction is important because for an appliance to contribute significant CO to the indoor environment it has to both produce CO and fail to get the combustion products out of the home. It is rare for induced-draft and power-vented appliances to release combustion products into the home unless there is a failure in the venting system.

Of the 111 furnaces that were tested, seven had pre-weatherization CO levels above 400 ppm in the flue with the maximum recorded value being over 2600 ppm. Six of these seven were natural-draft appliances that were replaced through the weatherization efforts (overall, about half of natural-draft furnaces in the study were replaced) and none of the seven homes with pre-weatherization furnace CO levels over 400 ppm had this problem following weatherization.

Water heaters are nearly all natural-draft. None of the 200 units in treatment homes had CO levels in the flue that exceeded 100 ppm, either before or after weatherization.

The comparison metric for rangetop burners and ovens was 800 ppm air-free CO, meaning that a calculation was done that removed the effects of dilution by air. This metric is used for appliance emissions standards for ovens and is more robust when comparing across units. Rangetop burners and ovens proved to be more difficult to measure. The same combustion analyzer was used; however, especially for rangetop burners, the exact location of the sensor can have a substantial impact on the results. Therefore, while the results can be considered indicative of the general levels of CO from these appliances there is substantial uncertainty on an individual unit.

For rangetop burners about 2% of burners – from about 4% of ranges – had measured levels above 800 ppm air-free with an average of 140 ppm air-free. There was no statistically-significant change following retrofit. This is not surprising since there were only two oven replacements and two range/oven cleanings among treatment homes.

For ovens, the data suggest that about 12% of ovens produce CO levels above 800 ppm air-free with the average at about half of the threshold. This shows that ovens are more likely than rangetop burners to produce elevated levels of CO in the indoor air.

Indoor Air CO Levels

In the WAP study, 59% of homes never had any event during the weeklong test period where the CO level exceeded 5 ppm, and 79% of homes never hit 10 ppm. The CO level reached a peak of 20 ppm in 9% of homes. Only 3% of all homes in Study 1 had CO levels above 5 ppm for 10% or more of the time.

In this study, further investigation was done in an attempt to determine the source of the elevated CO in three situations: average CO above 3 ppm for the entire week (9 homes), five or more discrete events over 20 ppm (11 homes), or any event over 35 ppm (21 homes). Some homes fell in more than one category. In some cases the cause was not identified. The most common identified sources of high peak CO were found to be gas-fired furnaces that were not venting properly (3 cases), gas-fired ovens that produced high CO (3 cases), and attached garages (including one that had no door between the house and the garage prior to weatherization). Unvented gas space heaters were also a cause in some homes with averages over 3 ppm, but in only one case did an unvented space heater produce CO over 20 ppm in the home.

In the HUD study, only 8% of homes had averages over the week-long pre-retrofit measurement of 4.5 ppm or greater, and this dropped to only 3% following weatherization. About 30% of homes reached a peak concentration of 9 ppm or greater, both pre-retrofit and post-retrofit. This is a larger percentage than in the WAP study, though the two studies together suggest a 20-30% prevalence of reaching 9-10 ppm within a weeklong test period. Only 3 homes pre-retrofit and 4 homes post-retrofit had any event of 20 ppm or greater. Further investigation suggested that gas-fired ovens were the most likely cause of high CO events. Figure 1 shows an example of this. The left side of Figure 1 shows the time-series of about 6 days at one home. These data were collected in January of 2013. This shows periodic rises each day, but with the last two days having much higher peaks. The right side of Figure 1 shows the same data plotted against time of day. There appears to be a rise starting in the late morning which usually does not get above 3 ppm but persists for several hours. This is likely vehicles starting in the garage, with a long period of slightly elevated CO in the home, though it could be related to cooking. However, the large peaks seen in the last two days are both at about the same time of day (about 7:00 p.m.) suggesting that they are related to cooking dinner.

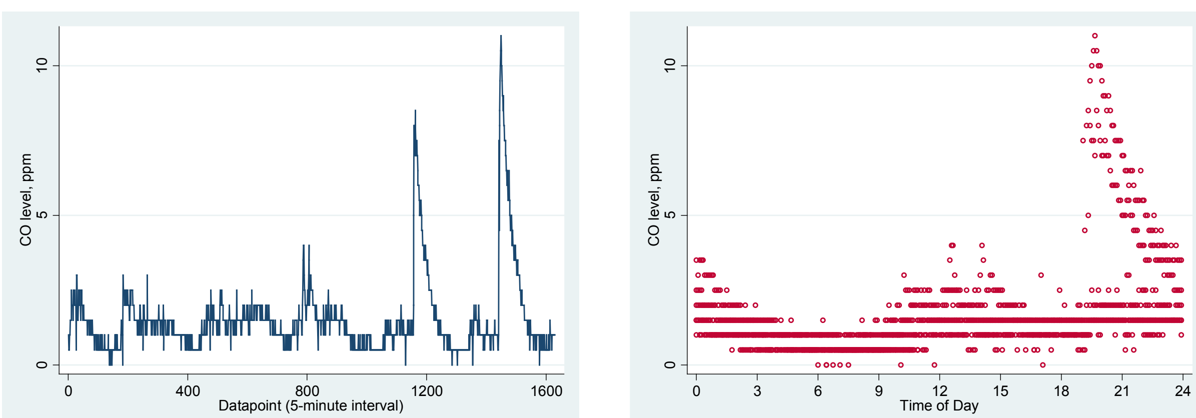

Figure 1 Time-series CO data in 5-minute intervals (left) and by time of day (right) for example home in HUD study.

CONCLUSIONS

The results of these two studies show that elevated CO in appliances occurs but it is not common in furnaces and water heaters, and that these are therefore not often the cause of high CO in homes. However, individual cases do exist where elevated CO produced by the furnace combined with venting problems did result in occasional CO levels peaking in excess of 20 ppm. No cases of high indoor CO were found that could be reliably sourced to a water heater.

Gas ovens and ranges can also be associated with elevated indoor CO levels, with ovens a more likely culprit. Ovens in the WAP study were more likely to exceed appliance standards for CO production, and they also tend to operate for longer periods of time than rangetop burners. This leads to ovens being more likely than rangetop burners to resulting in elevated peak CO levels in the indoor air to which residents can be exposed.

Attached garages were also identified as a source of CO. Other than the home that did not have a door between the house and the garage, CO in homes from garages is most likely to show a gradual rise and fall over a period of several hours while reaching an elevated low level but without as high of peaks as from appliances.

Weatherization programs do have the potential to identify and remediate some of these concerns through their programs. Remediation was most often effective when related to furnace replacements or air sealing between the living space and garage. Ovens and rangetop burners were not often addressed.

The event-driven nature of CO levels in homes means that short-term (period of less than 3 hours) monitoring of indoor air is not a reliable way to identify a CO concern in many cases. Direct appliance evaluation is more reliable, and long-term monitoring can help to identify persistent low-level issues such as from garages.

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