Distribution of CO in 30 Homes with Unvented Gas Fireplaces

Paul W. FRANCISCO[1], Jeffrey R. GORDON[1], and William B. ROSE[1]

[1] University of Illinois at Urbana-Champaign, Building Research Council, Champaign, IL

Abstract
As part of a field measurement project of unvented gas fireplaces in 30 homes, portable carbon monoxide sensors were located in several places in each home. This was done to assess the degree to which combustion by-products became distributed throughout the home. The sensors indicated that carbon monoxide levels began rising throughout the home almost immediately, at or near the one-minute sampling interval. The results show that, on average, the reading in the middle of the fireplace room was about 95% of the reading at the mantel. Readings throughout the rest of the home are comparable to each other and are between 75-80% of the reading at the mantel at peak concentrations. These results indicate that carbon monoxide concentrations from unvented fireplace combustion spread rapidly and rather uniformly throughout the house.

Keywords: unvented combustion, residential, field measurement, IAQ

Introduction

Unvented gas heating appliances are similar to other space heating and hearth products, with one exception – they don't have a chimney, flue or vent. For builders and homeowners this is appealing because no hole in the roof or walls is required, allowing for substantial installation savings and preventing potential leaks at the point of venting. Since the installation of unvented gas fireplaces does not require a chimney or any other vents, they can be easily installed almost anywhere. However, since unvented gas fireplaces release combustion products with potentially adverse health effects to the living space, they have remained controversial among the building science community.

From 2005-2007 field testing was performed in 30 homes that utilized these appliances. Testing at each home lasted for 3-4 days, and included measurements of carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x) and its components nitric oxide (NO) and nitrogen dioxide (NO_2), oxygen (O_2) depletion, and water vapor (H_2O) in a location approximately 6 feet away from the fireplace. Data were recorded every minute. Summary results from this project can be found in Francisco et al.[1]

In addition to the sampling location near the fireplace, water vapor and CO were also recorded using portable passive sensors in 5 locations throughout the home to assess the distribution of combustion products throughout the home. The results from the water vapor sensors have been published previously[2]. This paper presents the results from the portable CO sensors.

Methodology

At each home sensors were placed on the fireplace mantel, in the middle of the room in which the fireplace was located, on the opposite side of the room in which the fireplace was located, in an adjacent room (often, but not always, a kitchen), and a distant room (often, but not always, a bedroom).

In order to analyze the CO data for distribution throughout the house, the data from the CO sensors at each house were first viewed graphically to determine which fireplace usage cycle produced the largest CO signal. The primary reason why a single cycle was used is that the resolution of the sensors is about 0.5 ppm. Therefore, in order for the comparison between sensors to be as strong as possible the CO levels needed to be as high as possible. Figure 1 shows an example of the data and the selection of a cycle to analyze. This figure, which includes the data from both the mantel and distant sensor locations, shows several important features pertinent to this analysis. First, the distant bedroom sensor consistently indicated a lower CO concentration at that location than at the mantel. Second, the CO levels began to rise and fall at essentially the same time, within the 1-minute sampling interval, thus obviating the need to adjust for any time lag. Third, the rise in the evening of Feb. 4, which shows both a lower concentration than earlier periods and a greater difference between the mantel and the distant bedroom, was actually unrelated to the fireplace but rather was due to cooking in the kitchen.

Once a cycle was selected, the maximum CO concentration for each sensor location was determined. Selecting the maximum has two advantages. First, the sensor resolution is the smallest possible fraction of the signal. Second, it is at these maximum levels at which there is the greatest concern about exposures.

The resulting maximum values for each sensor location was regressed linearly on the mantel sensor values. The coefficient of the regression is an estimate of the percentage of the CO concentration at the mantel that reaches each of the other locations, i.e. for each additional ppm of CO at the mantel the coefficient indicates how much the concentration rises at each location.

In addition to the sample-wide results three homes are discussed individually. These homes each demonstrate interesting characteristics that are not reflected in the overall sample but which are worth discussion.

There were some homes in the sample at which results could not be determined. There were various causes of this, including extremely short cycles, very low concentrations (e.g. under 2 ppm such that the resolution of the sensors was a very large percentage of the signal), and failed sensors such that no data were recorded. The resulting dataset for this analysis comprised 18 homes.

Sample Characteristics

The homes in the study represented a sample of convenience. Homes were solicited via a university newsletter and word of mouth. The average age of the homes was about 35 years old, with a minimum of 3 years and a maximum of about 100 years. The average age of the fireplaces was over 6 years, with a minimum of 4 weeks and a maximum of 15 years. The average floor area of the homes was about 167 m^2, with a minimum of about 111 m^2 and a maximum of about 279 m^2. The average leakage of the homes was about 11.3 air changes at 50 Pa (ACH50) with a minimum of about 5.5 ACH50 and a maximum of about 23.4 ACH50.

Results

Figure 2 shows the maximum concentrations for each sensor location vs. the maximum concentration at the mantel, along with a regression line. These data are for the entire 18 home sample presented in this paper. Figure 2a shows the sensor in the middle of the fireplace room; 2b shows the sensor at the opposite side of the fireplace room; 2c shows the sensor in the adjacent room; and 2d shows the sensor in a distant room.

These regressions show that the CO concentration in the middle of the fireplace room is about 11% higher than the concentration at the mantel, though with a constant of about -2 ppm. The regression shows that the t-statistic on the constant is 2.43, which borders on statistical significance. If the regression was forced through zero then the coefficient would be 0.97. With either analysis, the data indicate that the concentration in the middle of the room with the fireplace is comparable to the concentration at the mantel.

The graphs for the opposite side of the fireplace room, adjacent room, and distant room all show that the concentration at these locations is typically lower than the concentration at the mantel. As the location is further from the mantel the degree of scatter increases, as evidenced by the lower R^2 values.

For the opposite side of the fireplace room and the adjacent room the concentration is about 80% of the value at the mantel. This drops to about 75% at the distant room. These results show that the concentration is typically fairly uniform throughout the house except in the immediate vicinity of the fireplace, at about 75-80% of the level near the fireplace. This is consistent with the results of Ferro et al.[3] who showed that concentrations of point-source contaminants may be only 20-30% lower in other rooms with open doors. High levels of airflow and/or mixing through open doors have also been shown by Miller and Nazaroff[4] and Sherman and Walker[5].

Figure 3 shows the CO data at Sites 26 (Figure 3a) and 31 (Figure 3b), for the mantel, opposite side of the fireplace room, and distant room.

In Site 26 the fireplace was located in the basement. This basement had been tightened but not insulated. The CO sensor in the distant bedroom was upstairs on the first floor.

There are two primary features of the data at this home. First, despite being upstairs, the CO concentration in the bedroom was comparable to the concentration at the opposite side of the fireplace room for most of the test, with the primary exception being the night of Jan. 23 and the morning of Jan. 24. It is likely that the door between the basement and the first floor was closed at this time.

The other feature of this graph is that there are very few times when there is not transient behavior. This makes it reasonable to compare the concentrations in different locations for the entire test period, not just one cycle. Regressions of each sensor on the mantel sensor show that concentration in the middle of the fireplace room was about 94% of the concentration at the mantel, the concentration at the opposite side was about 62% of the concentration at the mantel, and the two sensors upstairs (adjacent and bedroom) were about 54% and 56% that of the mantel, respectively. These percentages are lower than the sample average, but the qualitative result of the sensors beyond the middle of the fireplace room being comparable is consistent with the other homes.

In Site 31 the fireplace was in the living area, and the distant sensor was in the basement. The basement door was typically kept closed.

In this home the concentration at the opposite side of the fireplace room was about 90% that at the mantel, but the concentration in the basement rarely showed substantial evidence of a response to the fireplace operation. These data show the potential impact of closed doors on the concentration, especially when airflow driving forces (in this case, stack effect) do not promote transport of the CO to the other space (in this case, the basement).

Figure 4 shows the CO concentration and the air temperature at the mantel of Site 29. The temperature indicates when the fireplace was on.

This home was split into two parts, with the lower floor having been turned into an apartment. Both the apartment and the main residence had unvented gas fireplaces. The data indicate that the fireplace in the apartment was turned on for extended periods of time and that stack effect caused the by-products to rise and enter the main residence. This shows not only the potential impact of stack effect to transport CO to higher living areas, but also suggests substantial air leakage between the main residence and the apartment.

Conclusions

The data presented here demonstrate that it is typical for concentrations of combustion by-products from an unvented gas fireplace point source to rise throughout the house with little to no time lag. Concentrations on the opposite side of the fireplace room and throughout the house are typically about 70-80% that of the area in the immediate vicinity of the fireplace.

Individual homes show that door closures can have a substantial impact on the transport of the pollutant, and that transport mechanisms such as stack effect can have a significant impact on the vertical distribution of the pollutant.

References

1. Francisco, P.W., J.R. Gordon, and W.B. Rose. 2010. "Measured Concentrations of Combustion Gases from the Use of Unvented Gas Fireplaces", Indoor Air, in press.

2. Francisco, P. W., J. R. Gordon and W. B. Rose. 2009. "Indoor Moisture in 30 Homes Using Unvented Gas Fireplaces." *ASHRAE Transactions* **115**(1): 914-923.

3. Ferro, A.R.; Klepeis, N.E.; Ott, W.R.; Nazaroff, W.W.; Hildemann, L.M.; Switzer, P. 2009. "Effect of Interior Door Position on Room-to-Room Differences in Residential Pollutant Concentrations After Short-Term Releases", *Atmos. Environ.* **43**: 706-714.

4. Miller, S.L.; Nazaroff, W.W. 2001. "Environmental Tobacco Smoke Particles in Multizone Indoor Environments", *Atmos. Environ.* **35**: 2053-2067.

5. Sherman, M.H.; Walker, I.S. 2009. "Measured Air Distribution Effectiveness for Residential Mechanical Ventilation Systems", *HVAC&R Research J.* **15**: 211-230.

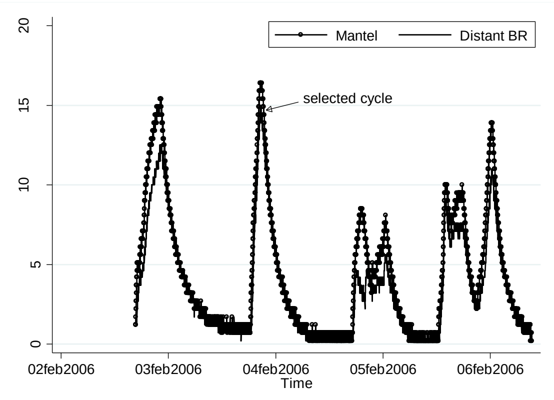

Figure 1. Example of carbon monoxide data and cycle selection for analysis.

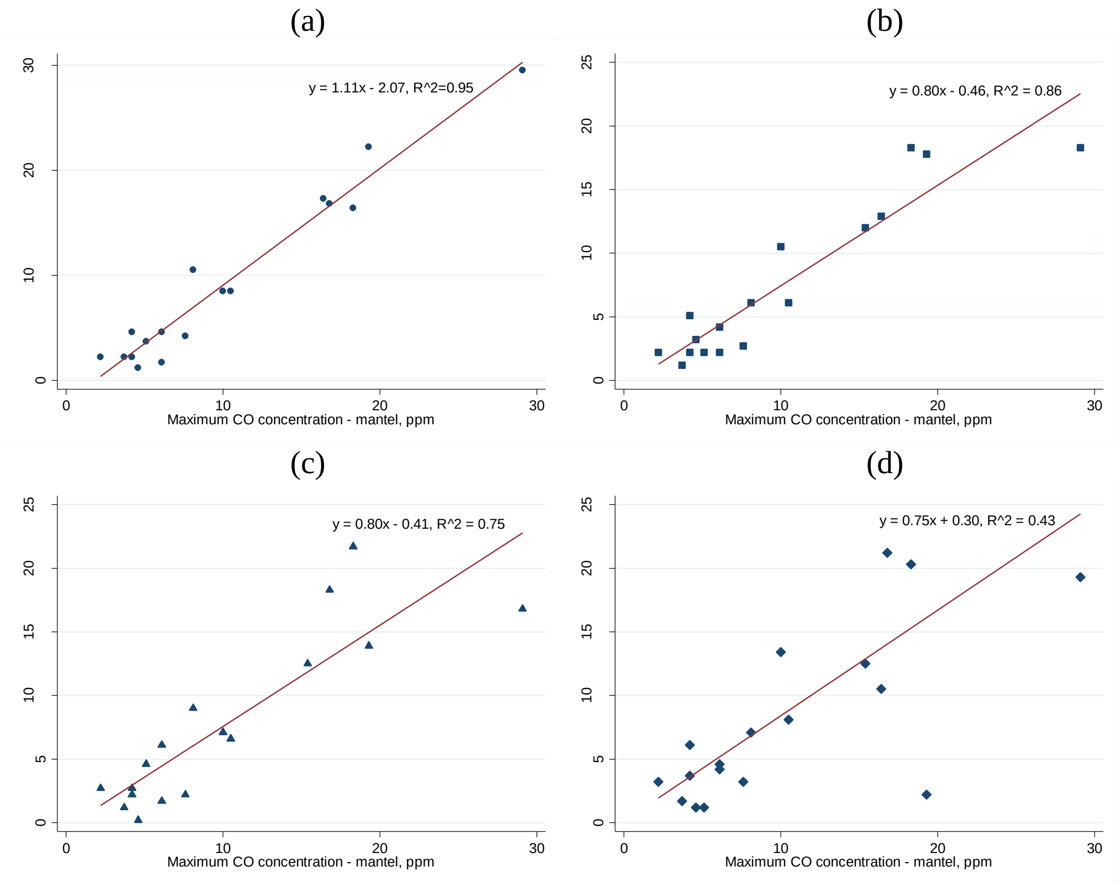

Figure 2. CO concentrations at each sensor location compared to at the mantel.

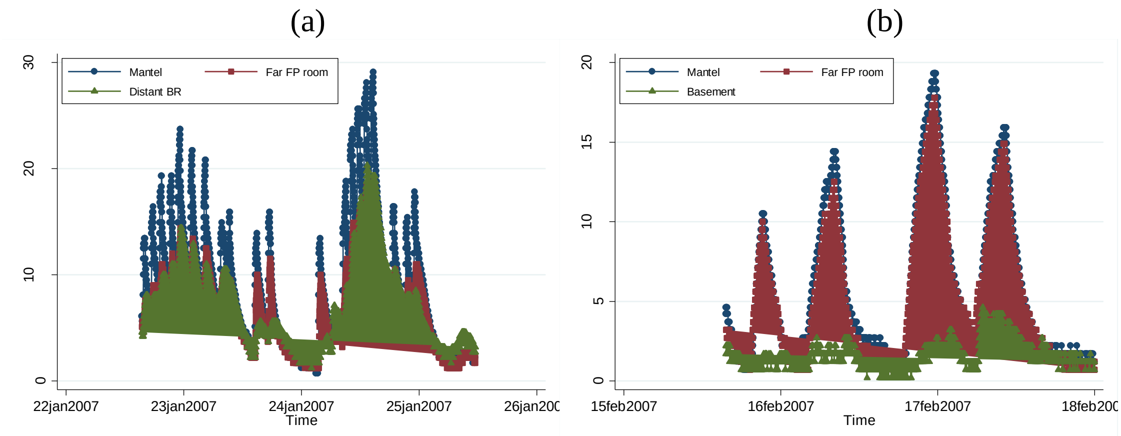

Figure 3. CO concentrations at Site 26 (3a) and 31 (3b).

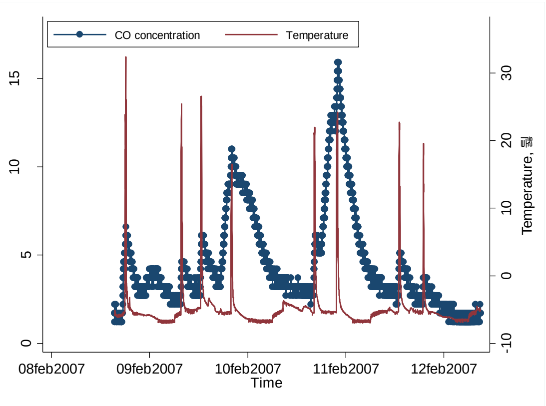

Figure 4. CO concentration and temperature at the mantel at Site 29.