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CHARACTERIZATION OF RESIDENTIAL AIR POLLUTION FROM UNVENTED KEROSENE HEATERS

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Abstract

This study investigated the generation of pollutants from unvented convective and radiant heaters in a residence over a 3 month period. The measured concentrations of carbon monoxide were low. However, under the conditions of use which were studied concentrations of SO_2, NO, NO_2, and CO_2 reached or exceeded levels recommended for indoor air. Further, it was demonstrated that using a semi-open door to provide "ventilation" did not reduce concentrations of pollutants to acceptable levels. A comparison of the measured concentrations to predicted concentrations based on mass balance modeling is also presented.

Introduction

Studies of emission rates from unvented kerosene heaters suggest that use of the heaters in residential settings may pose significant health hazards by releasing combustion products which can accumulate to unsafe levels.[1-5] Although measurements of air quality in residences are limited, observed concentrations have exceeded recommended indoor air quality guidelines.[6]

The purpose of the study presented in this paper was threefold; 1) to develop a data base for assessing exposure to emissions from kerosene heaters under conditions of routine use, 2) to determine if using heaters in a semi-open room is an effective way of providing "ventilation," and 3) to verify a predictive model that is based on mass balances.

Methods

The study was conducted during February-April, 1983 in a 213 sq. ft. room of a 1982 constructed house that was moderately insulated. The house has a gas furnace with forced air heat that was off during the heater test runs. No smoking or cooking occurred during the study period.

Environmental Protection Agency (EPA) approved analyzers including chemiluminescence for NO_x, infrared for CO, pulsed fluorescence for SO_2, and infrared for CO_2 were used. The Indianapolis Air Pollution Control Division performed the calibrations (traceable to the National Bureau of Standards) and weekly audits on the equipment. Temperature and relative humidity were monitored in the living room, in the bedroom, and in an open hall outside of the bedroom. Both parameters were also monitored outside of the house. Wind speed and wind direction data were obtained from the National Weather Service and the Indianapolis Air Pollution Control Board.

One convective heater (rated output: 8200 Btu/hr) and one radiant heater (rated: 9000 Btu/hr) were used in the study. Sampling probes were located six feet away from the heaters and three feet above the floor to simulate the breathing zone. The study was conducted with door width openings of 1 inch, 12 inches, and open door. Tests consisted of 3 to 5 hour burn times followed by one hour of decay. A room fan was operated to ensure mixing, and floor to ceiling concentrations varied by ± 10% from the breathing zone. All tests were performed with fuel from the same batch (0.07% S, 0.05% S) and fuel consumption was measured volumetrically. All tests were run in duplicate. Background levels of pollutants were also measured in the home during the study with and without the furnace operating and in the outside air.

Pollutant concentrations in the home were simulated based on a two compartment model developed by Shair for the National Kerosene Heater Association.[7] This model incorporates the convective transfer of heat and pollutants between the heated room and a second compartment representing the remainder of the house. In addition, pollutants are dissipated by convection to the outside atmosphere. Heating requirements are sufficient at steady-state to balance this convective heat loss as well as the conductive heat loss to both the outside and the remainder of the house. The model can simulate the operation of a heater in a closed room, an open house with complete mixing of the interior air, or intermediate cases in which the door between the heated area and the remainder of the house is partially open. The convective heat transfer term between rooms is modeled after the method of Lavery.[1]

Heat transfer coefficients (external--0.0956 Btu/hr-ft^3-°F; internal--0.293 Btu/hr-ft^3-°F) were estimated from the ASHRAE Handbook[8] based upon the construction specifications of the test home.

Results

Measured Pollutant Concentrations

Table 1 summarizes the measured steady-state pollutant levels for semi-open and open room cases. Generally, leaving the heater room door open to the rest of the house is effective in reducing pollutant concentrations; however, concentrations of potential health concern can still occur, particularly with the convective heater. ASHRAE[9] has recommended that indoor levels of pollutants not exceed 0.41 ppm NO, 0.05 ppm NO_2, 0.14 ppm SO_2, 9.0 ppm CO, and 0.25% CO_2. Even with the heater room door open, the measured concentrations of NO, NO_2, SO_2, and CO_2 from the convective heater were greater than the recommended guidelines, while NO_2 and CO_2 concentrations from the radiant heater exceeded the guidelines.

The variability in the measured NO, NO_2, and CO data from run to run reflects inherent variation that results from positioning the wick in the heater. In the case of CO an added source of variation is negative zero drift experienced with the infrared analyzer.

The use of the heaters in the semi-open room with a door width opening of 1 inch resulted in mean room temperature increases of 8.7 ^oF for the convective heater and 11 ^oF for the radiant heater--temperature increases that are not unreasonable in terms of normal heater use.

Ambient background levels were low during the study period. Mean background concentrations in the home were negligible for NO_2 and SO_2 both with the furnace on and with the furnace off. When the furnace was the only source in the house, NO concentrations averaged 0.119 ppm and CO concentrations averaged 1.1 ppm.

Modeling of Pollutant Concentrations

The purpose of modeling pollutant concentrations was to verify a mass balance model based on known inputs including pollutant decay rates, air exchange rates, source emission rates and heat transfer variables. Of these the source emission rates and pollutant decay rates are the most difficult to quantify.

Pollutant decay rates were determined under field conditions. Decay rates were calculated using the least squares correlation of the exponential decrease in concentration after the heater was turned off. The decay rates in Table 2 reflect both the air exchange rate and the volumetric reaction rates of the pollutant with surfaces of the room. Generally, expected trends in decay rates for pollutant species and door width openings were observed. The CO decay rate for the open door case, however, was higher than expected and this anomaly may be related to zero-drift during measurements. The observed decay rates for NO_2 and SO_2 were in the range of rates reported by other investigators[1]; however, the variation in reported ranges is large and actual values will vary from situation to situation.

Table 3 shows a comparison between a best fit source emission rate and source emission rates calculated for the heaters in this study based on fuel consumption. The best fit source emission rate was calculated using the mass balance model to minimize differences between measured and predicted pollutant concentrations. In general, there is good agreement between source emission rates for the convective heaters, considering the variablity that can result from heater operation and/or individual heater performance.

In the case of the radiant heater the calculated source emission rate is consistently lower than the best fit rate, and has a somewhat higher associated variabilty among different runs. The source emission rates per unit of fuel used are also lower than those reported by other investigators.[1] The most likely source of uncertainty in the calculated source emission rates is the estimation of an average decay constant for each pollutant.

The calculated source emission rates (based on fuel use) in Table 3 were used to predict pollutant concentrations in the room using the mass balance model. The differences between measured and predicted concentrations were tested using the Student's T-test. In general, the predicted concentrations were lower than and within 50% of the measured concentrations. The T-test showed a significant difference ($p=0.05$) between the measured and predicted concentrations in all cases except for NO, NO_2, and CO for the convective heater.

Conclusions

The routine use of kerosene heaters, particularly convective heaters, resulted in pollutant concentrations that exceeded recommended residential guidelines. Further, the use of a semi-open door or an open door to provide "ventilation" did not reduce pollutant concentrations to acceptable levels.

Kerosene heaters as a point source are difficult to characterize with precision. Heater performance can vary considerably in replicate runs because of the difficulty in positioning the wick identically each time, age of wick, and other operational factors. Another source of variation may be associated with fuel consumption among different heaters of the same model type. The mass balance model did predict steady-state pollutant concentrations that were within 50% of the measured concentrations. However, standardized testing protocols need to be developed for evaluating source emission rates and pollutant decay rates to improve model performance.

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Table 1. Measured Steady-State Pollutant Levels for Open and Semi-open Room Cases (Door Width = 1 inch, 12 inches, open).

Convective Heater (8200 Btu/hr)

	1" (n=15)		12" (n=42)		Open (n=42)	
	μ	$\sigma/\sqrt{n}$	μ	$\sigma/\sqrt{n}$	μ	$\sigma/\sqrt{n}$
NO (ppm)	0.943	0.036	0.640	0.017	0.474	0.032
NO_2 (ppm)	0.250	0.004	0.174	0.006	0.154	0.001
SO_2 (ppm)	0.121	0.004	0.117	0.004	0.099	0.004
CO (ppm)	2.7	0.0	1.8	0.1	1.3	0.1
CO_2 (%)	0.42	0.01	0.37	0.01	0.32	0.01
T Room (°F)	78	2.0	78	1.1	76	0.4
T Ambient (°F)	71	2.0	44	1.1	47	0.8
T House (°F)	68	1.8	67	1.3	70	0.4

Radiant Heater (9000 Btu/hr)

	1" (n=33)		12" (n=33)		Open (n=33)	
	μ	$\sigma/\sqrt{n}$	μ	$\sigma/\sqrt{n}$	μ	$\sigma/\sqrt{n}$
NO (ppm)	0.079	0.003	0.065	0.002	0.067	0.003
NO_2 (ppm)	0.063	0.002	0.071	0.004	0.057	0.005
SO_2 (ppm)	0.174	0.005	0.138	0.004	0.102	0.003
CO (ppm)	5.0	0.2	3.7	0.1	2.7	0.2
CO_2 (%)	0.56	0.01	0.50	0.02	0.45	0.02
T Room (°F)	82	0.9	80	1.1	72	0.7
T Ambient (°F)	37	1.2	44	1.3	44	0.9
T House (°F)	66	1.2	64	0.9	72	0.6

Table 2. Pollutant Decay Rates (hr^{-1}).

Door Width Opening

	1" (n=8)	12" (n=11)	Open (n=11)
	$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$
NO	1.28 ± 1.06	0.794 ± 0.282	0.784 ± 0.280
NO_2	1.95 ± 0.496	1.54 ± 0.547	1.27 ± 0.638
SO_2	2.16 ± 0.522	1.97 ± 0.547	1.65 ± 0.235
CO	1.06 ± 0.373	0.791 ± 0.237	1.12 ± 0.458
CO_2	0.840 ± 0.091	0.722 ± 0.095	0.642 ± 0.102

Table 3. Source Emission Rates (10^{-6} ft^3/Btu/hr).

	Convective	Best Fit	Radiant	Best Fit
NO	0.411 ± 0.105	0.436	0.014 ± 0.008	0.045
NO_2	0.211 ± 0.042	0.216	0.025 ± 0.008	0.055
SO_2	0.078 ± 0.010	0.150	0.079 ± 0.017	0.163
CO	1.26 ± 0.49	1.47	1.16 ± 0.48	2.25
CO_2	1376 ± 200	2260	1379 ± 240	2640

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