FIELD SURVEY OF INDOOR AIR POLLUTION IN RESIDENCES WITH SUSPECTED COMBUSTION-RELATED SOURCES

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Abstract

Thirty residences were monitored for nitrogen dioxide, carbon monoxide, formaldehyde, respirable suspended particles, and air exchange rate for forty-one one-week periods using integrating samplers. The residences were located in the northwest and central regions of New York State, U.S.A. Most of the homes had suspected combustion-related indoor pollution sources, including smokers, unvented kerosene-fired space heaters, gas-fired ranges, coal-burning stoves, wood-burning stoves, wood-burning fireplaces, gas-fired furnaces, and oil-fired furnaces. Average nitrogen dioxide levels were highest, up to 117 ppb, in homes with unvented kerosene-fired space heaters. Respirable suspended particulate levels were highest, up to 144 $\mu g/m^3$, in homes with smokers. Formaldehyde and carbon monoxide concentrations were generally low; however, one residence with new furnishings had an average indoor formaldehyde level of 151 ppb and one residence with an attached garage had an average indoor carbon monoxide level of 9 ppm.

Introduction

Elevated indoor pollutant levels have been observed in some homes with combustion appliances. Some of these appliances are unvented (e.g., gas-fired ranges and kerosene-fired space heaters) and indoor pollutant levels above outdoor levels have been observed (5,6,9). Other appliances such as gas-fired forced-air furnace systems are vented and, if operating properly, do not contribute to indoor pollution levels but can emit pollution indoors if they are not operating properly (5). Finally, appliances such as wood-burning stoves, which are vented devices, can emit trace amounts of pollutants indoors during normal starting, stoking, and reloading operations or can leak pollutants continuously into the indoor environment through cracks in the stove or vent system (7,10). The above appliances have led to elevated indoor levels of nitrogen dioxide (NO_2), carbon monoxide (CO), and respirable suspended particles (RSP).

This work, part of a larger on-going indoor air pollution field study funded by the Niagara Mohawk Power Corporation and the New York State Energy Research and Development Authority, was designed to investigate the pollutant concentrations in homes with potential

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combustion-related sources. Twenty-five homes with a wide variety of potential sources were studied. Potential sources included cigarette smokers, forced-air furnaces, wood- and coal-burning stoves, gas-fired ranges, kerosene-fired space heaters, and fireplaces. In addition, homes without potential combustion-related sources were monitored.

Experimental

All homes were monitored for NO_2, CO, RSP, formaldehyde (HCHO), and air exchange rate using integrating monitors. NO_2 was monitored using a passive diffusion sampler developed by Palmes (8). CO was monitored using an electrochemical sampler with integrating electronics. RSP, particles less then 3.5 microns in diameter, were collected on a Teflon filter after the large particles (>3.5 μm) were removed by a 10-mm nylon cyclone. The filter samples were gravimetrically analyzed. HCHO was monitored with a passive diffusion sampler developed at the Lawrence Berkeley Laboratory (3). Finally, the air exchange rate of each house was monitored using passive perfluorocarbon emitters and collectors (2). Technically, this method slightly biases the results; actual air exchange may be slightly higher than reported here.

All homes were monitored during the winter months when the usage of some sources is greatest. Several homes had multiple potential sources. Upon interviewing the homeowners it was determined whether the potential sources were used during the same time periods or if one potential source such as a kerosene-fired space heater was used as a substitute for another potential source such as a wood-burning stove. If the former was the case, the house was operated in its normal fashion during the one-week monitoring period. If the latter was the case, as it was for one house, the homeowner was asked to use only one potential source during each one-week monitoring period, and several weeks of sampling were conducted.

Results and Discussion

Table 1 summarizes the air exchange rates, volumes, and indoor and outdoor air pollution levels for the forty-one weeks of indoor air sampling. Houses that were monitored for more than one week are coded with three digits instead of the normal two digits. Homeowners were asked to log, via a questionnaire, their usage of each potential indoor air pollution source. In general, the questionnaires were completed properly. However, the usage data could not be assembled in this short paper and will be only briefly mentioned.

Most of the elevated indoor NO_2 concentrations were associated with the indoor use of kerosene heaters. During weeks when kerosene heaters were the only source (house codes 20, 32-1, and 50-2) the NO_2 levels ranged from 25 ppb to 117 ppb. For comparison the long-term (one-year average) U.S.A. outdoor NO_2 standard is 50 ppb (11). The wide variation observed reflects, in part, the difference in usage. The kerosene heater usage was 28.5 kerosene-heater hours per day (KHh/d) for house 20, 42.5 KHh/d for house code 32-1, and 3.9 KHh/d for house code 50-2. Assuming steady-state well-mixed conditions and an NO_2 indoor reactivity rate of

0.25 h^{-1} the implied NO_2 source strengths of the kerosene heaters were between 18 and 37 cm^3/h per heater. Previously published kerosene heater data measured NO_2 source strengths ranging from 27 to 92 cm^3/h per heater (10). Although the source strength analysis in this paper is very rough and very sensitive to the NO_2 reactivity assumption, it does show that the kerosene heater usage data and other collected information are consistent with the observed indoor NO_2 concentrations.

The only elevated NO_2 concentration not associated with kerosene heaters is the 29 ppb observed in a house with a propane-fired range (house code 50-6). During the measurement week the occupants used the top burners an average of 7.2 burner-hours per day and used the oven an average of 2.7 hours per day. The authors feel that this high usage rate may not be normal since relatives stayed with the homeowner during the entire monitoring period leading to high cooking activity.

Elevated RSP concentrations were always observed in homes with smokers, were usually observed in homes with wood-burning stoves and fireplaces, and was once observed in a house with no source (house 14) and a house with kerosene heaters (house code 32-1). For homes with just smokers, the indoor RSP levels ranged form 29 to 144 μg/m^3. For comparison the U.S.A. annual outdoor total suspended particulate primary standard is 75 μg/m^3 (11), however indoor-generated particles were not a consideration in the development of the outdoor standard.

Using a published particulate emission rate for sidestream cigarette smoke of 10,800 μg/cigarette (4), the homeowner's source usage log, and several assumptions (e.g., the indoor particulate reactivity term is zero), a "predicted" average indoor RSP level can be calculated. For homes with smoking as their only source, the predicted RSP concentrations were approximately 170, 130, 60, and 70 μg/m^3 for house codes 02-1, 02-2, 36, and 50-2, respectively. (The average number of cigarettes smoked each day were 30.5, 21.5, 21.7, and 12.7 for house codes 02-1, 02-2, 36, and 50-5, respectively.) The rough predicted values compare well with the actual measured RSP concentrations of 144, 73, 85, and 29 μg/m^3 for house codes 02-1, 02-2, 36, and 50-5, respectively. The average of the predicted concentrations was 30% higher than the average of the measured concentrations. There are numerous reasons why exact correlations are not expected, including the incomplete inventory of particulate sources, the lack of good indoor air mixing (an assumption used in calculating the predictive values), the possible incomplete logging of the number of cigarettes smoked, a non-zero indoor reactivity term, and the inclusion of volatile compounds in the sidestream cigarette RSP emission rate.

In general the HCHO and CO concentrations were low. This may not be surprising for HCHO since HCHO concentrations tend to be low during the winter months when the air is dry (1). One house (house 45) with new paneling and new furnishings had an HCHO concentration of 151 ppb. It was also one of the few houses monitored in May. The highest carbon monoxide level was 9 ppm in a house with smokers and an attached garage (house 55). Although other houses had attached garages, this was the only house that had both an attached garage and elevated CO levels. The CO monitors suffered from drift over the one-week period and "post-sampling" calibrations were performed on the instruments to correct for drift. In addition, spot measurements of CO concentrations were made at the beginning and end of each monitoring period. However, these actions were only partial solutions and the CO concentrations in Table 1 have a high unquantifiable uncertainty associated with them.

Several suspected indoor pollution sources (e.g., gas-fired and oil-fired furnaces) did not signficantly increase the indoor air pollution levels in this study (see Table 1). Since gas-fired and oil-fired furnaces would emit pollution indoors only if malfunctioning we would expect only a few percent to be indoor air pollution sources. This study was not designed to detect a small percentage of malfunctioning furnaces.

Conclusions

Of the combustion-related indoor air pollution sources investigated in this report, kerosene-fired space heaters, smokers, and wood-burning stoves caused the highest indoor pollutant levels. Kerosene heaters were responsible for high indoor NO_2 concentrations while smokers and wood-burning stoves were associated with high RSP levels. Rough calculations showed a correlation between source usage and indoor pollutant concentrations for homes with kerosene heaters and smokers. In addition, wood-burning stoves were implicated as a source of indoor respirable suspended particulates. Other combustion sources, primarily gas-fired and oil-fired furnaces, were not found to be indoor air pollution sources, but this small data set cannot be generalized. Follow-up studies of selected houses are under way to determine, among other factors, indoor pollutant reactivity rates, indoor pollutant mixing factors, and combustion appliance pollutant source strengths.

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References

(1) Andersen, I., Lundqvist, G.R., and Molhave, L. Indoor air pollution due to chipboard used as a construction material. Atmospheric Environment, 1975, 9, 1121-1127.

(2) Dietz, R.N., and Cote, E.A. Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique. Environment International, 1982, 8, 419-433.

(3) Geisling, K.L., Tashima, M.K., Girman, J.R., Miksch, R.R., and Rappaport, S.M. A passive sampling device for determining formaldehyde in indoor air. Environment International, 1982, 8, 153-158.

(4) Girman, J.R., Apte, M.G., Traynor, G.W., Allen, J.R., and Hollowell, C.D. Pollution emission rates from indoor combustion appliances and side-stream cigarette smoke. Environment International, 1982, 8, 213-221.

(5) Hollowell, C.D., Budnitz, R.J., and Traynor, G.W. Combustion-generated indoor air pollution, in Proceedings of the Fourth International Clear Air Congress. Tokyo, Japan; The Japanese Union of Air Pollution Prevention Associations, 1977, pp. 684-687.

(6) Melia, R.J.W., Flores, C. du V., Darby, S.C., Palmes, E.D., and Goldstein, B.D. Differences in NO_2 levels in kitchens with gas and electric cookers. Atmospheric Environment, 1978, 12, 1279.

(7) Moschandreas, D.J., Zabransky, J. Jr., and Rector, H.E. The effects of woodburning on the indoor residential air quality. Environment International, 1980, 4, 463-468.

(8) Palmes, E.D., Gunnison, A.F., DiMattio, J., and Tomczyk, C. Personal sampler for nitrogen dioxide. American Industrial Hygiene Association Journal, 1976, 37, 570.

(9) Spengler, J.D., Duffy, C.P., Letz, R., Tibbitts, T.W., and Ferris, B.G. Jr. Nitrogen dioxide inside and outside 137 homes and implications for ambient air quality standards and health effects research. Environmental Science and Technology, 1983, 17, 164-168.

(10) Traynor, G.W., et al., Indoor air pollution from portable kerosene-fired space heaters, wood-burning stoves, and wood-burning furnaces. Proceedings: Residential Wood and Coal Combustion, Pittsburg, PA; Air Pollution Control Association, 1982.

(11) U.S.A. Government, Code of Federal Regulations, Title 40, Section 50.8, 1975.

Table 1. Summary of one-week average indoor air pollution data.

Source/ house code	Air exchange rate[a] (h^{-1})	House volume (m^3)	NO_2[a] (ppb) In	NO_2[a] (ppb) Out	CO (ppm) In	CO (ppm) Out	RSP (ug/m^3) In	RSP (ug/m^3) Out	HCHO[a] (ppb) In
No Source									
14	0.11 ± 0.03	350	<1	4 ± 1	<1	<1	87	9	77 ± 3
16	0.24[b]	508	<1	6 ± 1	<1	<1	17	-	26 ± 6
24	0.40[b]	329	3 ± 1	12 ± 2	<1	<1	16	14	34 ± 4
50-1	0.15 ± 0.02	644	2 ± 1	5 ± 1	1	<1	16	1	7 ± 1
New Furnishings									
23	0.25 ± 0.04	429	2 ± 2	8 ± 3	<1	<1	19	9	61 ± 1
45	0.13 ± 0.02	483	2 ± 1	5 ± 0	<1	<1	19	9	151 ±38
61	0.26[b]	480	2 ± 1	6 ± 1	<1	<1	21	15	23 ± 3
Smokers (S)									
02-1	0.17 ± 0.03	473	3 ± 1	10 ± 2	3	<1	144	15	60 ±10
02-2	0.16 ± 0.02	473	5 ± 1	4 ± 1	<1	<1	73	9	56 ±10
36	0.37 ± 0.18	455	2 ± 1	9 ± 0	1	<1	85	9	40 ±10
50-5	0.12 ± 0.00	644	3 ± 1	2 ± 1	1	<1	29	7	32 ± 2
Kerosene-fired space heater (KH)									
20	0.30[b]	468	84 ±17	5 ± 2	5	<1	10	11	31 ±12
32-1	0.29 ± 0.12	701	117 ± 2	5 ± 1	1	<1	88	6	32 ± 2
50-2	0.13 ± 0.01	644	25 ± 7	3 ± 1	1	<1	25	4	25 ± 3
Wood-burning stove (WS)									
25	0.10 ± 0.01	733	1 ± 1	9 ± 1	<1	<1	40	9	31 ± 2
44	0.10[b]	606	5 ± 2	8 ± 4	<1	<1	8	8	36 ±11
51-1	0.12 ± 0.00	443	2 ± 1	9 ± 1	4	<1	68	21	12 ± 6
Coal-burning stove (CS)									
31	0.11 ± 0.02	1020	4 ± 1	10 ± 0	1	<1	12	11	28 ± 4
Fireplace w/wood (FW)									
47	0.15 ± 0.04	433	2 ± 1	15 ± 6	<1	<1	42	24	19 ± 2
50-3	0.16 ± 0.05	644	4 ± 1	4 ± 0	<1	<1	68	10	18 ± 2
Fireplace w/coal (FC)									
50-4	0.11 ± 0.01	644	2 ± 1	5 ± 1	<1	<1	14	10	19 ± 2
Gas-fired range (GR)									
05-2	0.28 ± 0.04	472	3 ± 1	6 ± 1	<1	<1	6	8	56 ± 5
50-6	0.13[c]	644	29 ± 8	2 ± 0	1	<1	20	4	36 ± 2
Gas-fired furnace (GF)									
01	0.30 ± 0.08	315	3 ± 1	18 ± 2	<1	<1	15	12	26 ± 2
21	0.32 ± 0.12	379	2 ± 1	11 ± 1	<1	<1	14	9	48 ± 1
43	0.32[b]	652	6 ± 2	14 ± 0	<1	<1	25	21	17 ± 3
Oil-fired furnace (OF)									
17	0.35 ± 0.11	682	6 ± 4	3 ± 2	<1	<1	16	8	23 ± 3
38	0.06 ± 0.01	798	1 ± 0	7 ± 1	<1	<1	18	17	27 ± 5
56	0.32[b]	588	5 ± 1	10 ± 2	<1	<1	14	13	22 ± 2
Combination of sources									
03 (S,WS)	0.27 ± 0.01	289	3 ± 1	6 ± 1	1	<1	80	7	24 ± 3
05-1 (WS,GR)	0.33 ± 0.10	472	6 ± 3	4 ± 1	<1	<1	23	10	62 ± 2
10 (OF,SW)	0.07[b]	690	4 ± 1	<1	<1	<1	22	20	64 ±21
18-1 (S,KH,GR)	0.57 ± 0.23	441	58 ± 2	12 ± 1	<1	<1	123	9	39 ± 6
18-2 (S,KH,GR)	0.57[c]	441	63 ±14	9 ± 4	1	<1	48	28	32 ± 4
22 (CS,WS)	0.17[b]	697	<1	8 ± 1	<1	<1	9	20	20 ± 3
32-2 (WS,KH)	0.33 ± 0.11	701	44 ± 1	8 ± 0	1	<1	32	7	46 ± 5
32-3 (CS,KH)	0.14 ± 0.11	701	9 ± 2	8 ± 1	<1	<1	19	6	53 ± 7
33 (WS,KH)	0.24 ± 0.16	579	46 ±23	7 ± 0	<1	<1	21	5	22 ±12
51-2 (WS,GR)	0.13 ± 0.00	443	2 ± 1	6 ± 1	3	<1	50	12	13 ± 3
55 (S,AG[d])	0.09 ± 0.00	270	1 ± 0	<1	9	<1	78	5	47 ± 1
60 (S,GR,GF)	0.11[b]	468	4 ± 2	5 ± 6	1	<1	103	18	59 ± 5

[a]Reported standard deviations are based on multiple measurements at different indoor locations.

[b]Based on average ratio of the measured air exchange rate to the air exchange rate at 50 pascals (0.049 ± 0.029).

[c]Average air exchange rate of house measurements made during other time periods.

[d]Attached garage.