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INDOOR AIR POLLUTION AND INTER-ROOM POLLUTANT TRANSPORT DUE TO UNVENTED KEROSENE-FIRED SPACE HEATERS

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Abstract

Two kerosene-fired space heaters, one white-flame convective and one blue-flame radiant, were operated in the master bedroom of an unoccupied house under several simulated use conditions. Tests were conducted with the bedroom door and outside window closed, with the door closed and the window open 2.5 cm, with the door open 2.5 cm and the window closed, and with the door wide open and the window closed. The heaters were operated until an 8°C temperature rise was achieved in the room. Increases in bedroom concentrations of CO, CO_2, NO, NO_2, and O_2 are reported. The increases in CO_2 levels ranged from 2440 to 5440 ppm while the increases in NO_2 levels ranged from 0.12 to 0.60 ppm. In addition, inter-room pollutant transport rates are reported for tests conducted with the window closed. While inter-room pollutant transport rates were less than 10 m^3/h with the bedroom door closed, they were 30 $\pm$ 10 m^3/h with the bedroom door open 2.5 cm, and ranged from 190 m^3/h to 3400 m^3/h with the door fully open (74 cm).

Introduction

The indoor use of unvented kerosene-fired space heaters in the U.S.A. has increased dramatically over the last several years due to increased energy costs. Because these devices are not vented to the outside, the pollutants they emit can have a detrimental effect on the quality of indoor air. Past studies have concentrated on the quantification of pollutant emission rates from unvented kerosene-fired space heaters (2,4,6). Results of these studies have shown that kerosene-fired space heaters can emit CO, CO_2, NO, NO_2, formaldehyde and respirable particles while consuming oxygen. Laboratory-derived emission rates coupled with indoor air quality modeling indicate that NO_2 concentrations exceed the California, U.S.A. outdoor guideline and CO_2 concentration can exceed the U.S.A. occupational guideline under certain operating conditions.

Experiments

This study measured the indoor pollutant levels from operating an unvented kerosene-fired space heater in an unoccupied house under several realistic use-patterns. The house is located in Truckee, California, U.S.A. (elevation: 1800 m). It is a ranch-type structure with a volume of 236 m^3. The house has a long straight hallway (5.4 m x 2.4 m x 0.93 m) which allows access to the bedrooms. The master bedroom door is at the end of the hallway furthest from the living room and kitchen.

The convective and radiant heaters were operated in the master bedroom until the bedroom air temperature increased at least 8°C. This procedure was followed under several operating conditions: first, the hinged bedroom door (to the rest of the house) was closed and the sliding window (to the outside) was closed; second, the bedroom door was opened 2.5 cm and the window was closed; third, the bedroom door was fully opened (74 cm) and the window was closed; and fourth, the bedroom door was closed and the window was opened 2.5 cm. The bedroom door opening is 204 cm high and the bedroom window opening is 101 cm high. All other interior doors,except closet and bathroom doors,were open for all tests and all other exterior doors and windows were closed for all tests.

The instrumentation used in this study has been described previously (1). Pollutant concentration at three indoor locations (living room, kitchen, and bedroom) and one outdoor location were monitored on a rotating basis every 24 minutes (6 minutes at each location). Temperature was monitored at each sample location. The bedroom temperature and air sampling probes were 1.5 m above the floor and were not in the path of the heater plume.

Inter-room pollutant transport rates were calculated for tests with the bedroom window closed using CO_2 concentration data and a two-compartment mass-balance model with several simplifying assumptions. The bedroom was treated as one compartment with a volume of 31 m^3 while the remainder of the house was the other compartment having a volume of 205 m^3. House and room volumes were measured by injection of a tracer gas under well-mixed conditions. The primary simplifying assumption used to calculate inter-room pollutant rates was that the flows out of each compartment to the outside are equal to the flows into each compartment from the outside. This was plausible because the large indoor/outdoor temperature differences, the low local wind speeds, and the wind-protected location of the house allowed us to assume that the stack effect, as opposed to the wind effect, was the primary driving force for infiltration in this house. Therefore, we were able to assign a portion of the total-home infiltration air flow rate, measured by CO_2 decay, to the bedroom and the remainder to the rest of the house. The division of infiltration air flow was based on the length of wall exposed to the outside.

Results and Discussion

Table 1 summarizes some of the test results including air exchange rate estimates, temperature data, and net increases in bedroom pollutant concentrations. CO_2 was the only pollutant with a significant background concentration, ranging from 360 ppm to 990 ppm with a mean of 580 $\pm$ 190 ppm. The average fuel consumption rates were 7300 $\pm$ 1200 kJ/h for the convective heater and 6400 $\pm$ 300 kJ/h for the radiant heater.

An important observation from the results of these tests is that moderate increases in ventilation rates, a result of opening a window or door 2.5 cm, do not necessarily reduce the peak pollutant concentrations because the heater must operate longer to achieve the same temperature rise. As expected, CO concentrations were highest when the radiant heater was used and NO concentrations were highest when the convective heater was used. However, NO_2 concentrations, although widely varying, were similar for both the convective and radiant heaters. The range of NO_2 concentrations was from 0.12 to 0.60 ppm for the convective heater tests and was from 0.12 to 0.52 ppm for the radiant heater tests. These numbers can be compared to the short-term (one-hour average) California, U.S.A. outdoor pollution NO_2 standard of 0.25 ppm (3).

Increases in bedroom CO_2 concentrations ranged from 2440 to 5440 ppm, excluding Test 1A which had a temperature increase greater than 10°C. Actual peak bedroom CO_2 concentrations ranged from 2870 to 5970 ppm excluding Test 1A. These numbers can be compared to the short-term (eight-hour average) U.S.A. occupational CO_2 standard of 5000 ppm (5).

Inter-room pollutant transport rates were calculated for all tests with the bedroom window closed. During the tests with the bedroom door closed and with the bedroom door open 2.5 cm there were substantial differences between the bedroom and kitchen/living room concentrations for at least 90 minutes after the heaters were shut-off allowing us to calculate inter-room flow rates during this period. Reported inter-room flow rates and average inter-room temperature differences for these test types are time-weighted averages over a minimum time period of 120 minutes. When the bedroom door was closed the inter-room flow rate averaged 6 $\pm$ 3 m^3/h. This corresponds to an inter-room air exchange rate (relative to the bedroom volume) of 0.2 h^{-1}. This number can be compared with the values of 0.35 to 0.50 h^{-1} in the third column of Table 1 which represent the total flow of air out of the bedroom for these cases. Average inter-room temperature differences were in the range of 3 to 5°C. When the bedroom door was open 2.5 cm, the average inter-room flow rate was 30 $\pm$ 10 m^3/h which corresponds to an inter-room air exchange rate of 1 h^{-1}. Inter-room temperature differences for these tests were in the range of 2 to 3°C.

When the bedroom door was wide open, the inter-room flow rates were so high that they could only be calculated while the heater was operating. Figure 1 shows the time-dependent inter-room flow rates and inter-room temperature differences for the convective and radiant heater tests. Estimates of the relative errors for these flow rate data are on the order of 30%. These rates are considerably higher than those with the door closed and the door open 2.5 cm. At the end of the convective heater test, the bedroom CO_2 concentration was almost identical to the living room and kitchen values. We hypothesize that the larger inter-room pollutant transport rate of the convective heater test may be due to the greater heat output of the convective heater and/or to the larger vertical temperature gradient in the bedroom during the convective test. The latter explanation is plausible since virtually all of the heat from the convective heater is contained in its plume while the radiant heater's output has both convective and radiant components.

Conclusions

The use of a kerosene heater in a bedroom under a wide variety of ventilation conditions results in NO_2 and CO_2 concentrations that are a significant fraction of or in excess of state or federal U.S.A. air quality guidelines. Moderate increases in ventilation rates obtained by slightly opening a window or door do not necessarily reduce peak pollutant concentrations since the heaters must be operated for longer periods of time to obtain the same increase in room temperature. Inter-room pollutant transport rates, however, can be sufficiently high to be an important mechanism for the dilution of pollutants generated in a single room.

Acknowledgements

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References

(1) Girman, J.R., Allen, J.R., Apte, M.G., Martin, V.M., and Traynor, G.W. Pollutant emission rates from unvented gas-fired space heaters: a laboratory study. Lawrence Berkeley Laboratory Report LBL-14502, Berkeley, California, 1983.

(2) Leaderer, B.P. Air pollutant emissions from kerosene-fired heaters. Science, 1983, 218, 1113-1115.

(3) State of California, California Administrative Code, Title 17, Subchapter 1.5, Section 70100, 1977.

(4) Traynor, G.W., Allen, J.R., Apte, M.G., Girman, J.R., and Hollowell, C.D. Pollutant emissions from portable kerosene-fired space heaters.

Environment Science & Technology, 1983, 17, 369-371.

(5) U.S.A. Government, Code of Federal Regulations, Title 29, Section 1910.1000, 1979.

(6) Yamanaka, S., Hirose, H., and Takada, S. Nitrogen oxides emissions from domestic kerosene-fired and gas-fired appliances. Atmospheric Environment, 1979, 13, 407-412.

Table 1. Peak pollutant concentration (less background) in a bedroom from using an unvented kerosene-fired space heater.

Test condition/ heater type	Combustion time (min)	Bedroom[a] decay rate (h^{-1})	House air exchange rate (h^{-1})	Mean outdoor temp. (°C)	Initial[b] bedroom temp. (°C)	Bedroom temp. increase (°C)	Peak pollutant concentration (less background)[c] (ppm) CO	CO_2	NO	NO_2	O_2
Door/window closed											
Convective heater											
Test 1A	50	0.43	--	-1.7	12.4	13.5	0.9	7620	4.63	0.19	-10700
Test 1B	45	0.45	--	-2.1	12.7	8.7	2.7	5440	2.15	0.57	- 6800
Test 1C	22	0.35	--	8.5	12.8	8.3	1.1	3460	1.96	0.12	- 5500
Test 1D	24	0.38	--	2.7	12.4	9.9	0.0	3790	1.99	0.24	- 5100
Radiant heater											
Test 2A	50	0.39	--	-3.7	12.7	8.7	17.6	4400	0.06	0.37	- 6900
Test 2B	31	0.50	--	-0.2	11.8	8.4	13.0	3300	0.19	0.52	- 4800
Door open 2.5 cm/window closed											
Convective heater											
Test 3A	62	--	0.25	-0.0	14.5	8.6	1.2	4860	2.37	0.43	- 6500
Radiant Heater											
Test 4A	56	--	0.27	-2.3	12.8	8.6	11.8	3870	0.13	0.22	- 5100
Door open 74 cm/window closed											
Convective heater											
Test 5A	133	--	0.35	-5.5	11.6	8.4	0.6	2440	1.54	0.13	- 4200
Radiant heater											
Test 6A	166	--	0.29	0.9	12.4	8.1	8.9	2670	0.09	0.12	- 4500
Door closed/window open 2.5 cm											
Convective heater											
Test 7A	46	0.99	--	3.5	12.7	8.4	1.9	4750	2.16	0.60	- 6400
Test 7B	25	0.89	--	-1.4	10.1	8.6	2.2	2610	1.17	0.31	- 3500
Radiant heater											
Test 8A	52	1.17	--	-3.7	12.8	8.4	14.6	4120	0.10	0.28	- 5800

[a] Represents total exfiltration to outside and to rest of house.
[b] Approximately the same as the initial house temperature.
[c] CO_2 indoor background concentrations were significant, ranging from 360 ppm to 990 ppm (mean = 580 ± 190 ppm). Pollutant standards are given in the text.

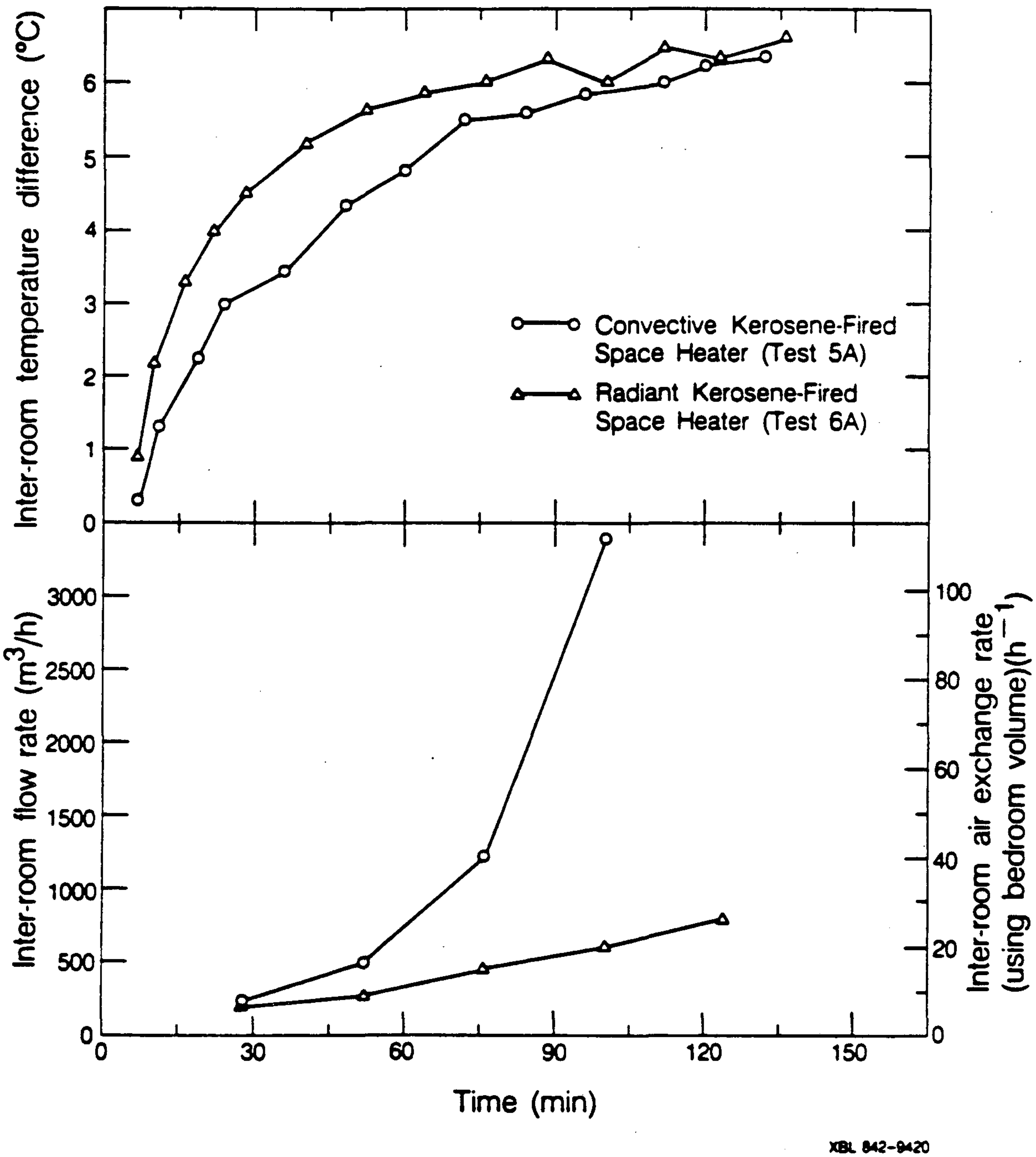

Figure 1. Inter-room temperature differences and air flow rates due to the use of a kerosene-fired space heater in a 31-m^3 bedroom. Flow rates were calculated using a two-compartment mass-balance model between the master bedroom and the rest of the house. The bedroom door was fully open during these tests.