Title
INDOOR AIR POLLUTION FROM PORTABLE KEROSENE-FIRED SPACE HEATERS, WOOD-BURNING STOVES, AND WOOD-BURNING FURNACES

Author
Traynor, G.W.

Publication Date
1982-03-01

LBL-14027

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

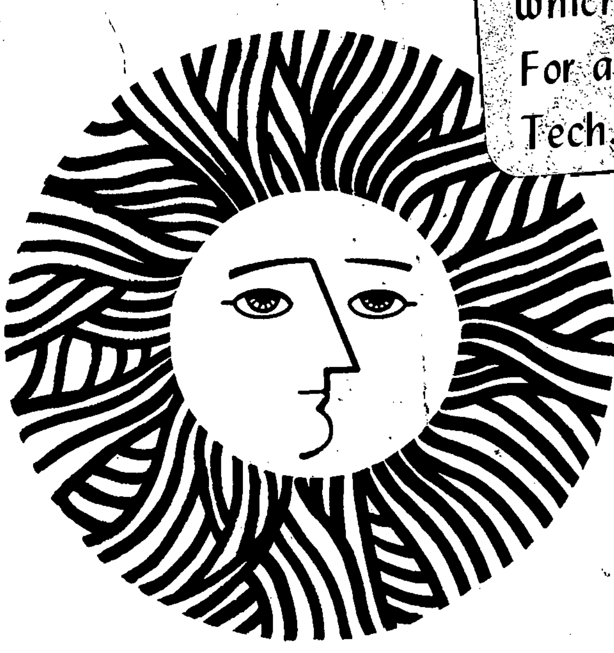
ENERGY & ENVIRONMENT DIVISION

Presented at the APCA Specialty Meeting on Residential Wood and Coal Combustion, Louisville, KY, March 1-2, 1982

INDOOR AIR POLLUTION FROM PORTABLE KEROSENE-FIRED SPACE HEATERS, WOOD-BURNING STOVES, AND WOOD-BURNING FURNACES

Gregory W. Traynor, James R. Allen, Michael G. Apte, James F. Dillworth, John R. Girman, Craig D. Hollowell, and James F. Koonce, Jr.

March 1982



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

Presented at the APCA
Specialty Meeting on Residential
Wood and Coal Combustion, Louisville, KY
March 1-2, 1982.

LBL-14027
EEB-Vent 82-3

INDOOR AIR POLLUTION FROM PORTABLE KEROSENE-FIRED SPACE HEATERS, WOOD-BURNING STOVES, AND WOOD-BURNING FURNACES

Gregory W. Traynor, James R. Allen, Michael G. Apte,
James F. Dillworth, John R. Girman, Craig D. Hollowell, and James F. Koonce, Jr.

Building Ventilation and Indoor Air Quality Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

March, 1982

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division, and by the Director, Office of Energy Research, Office of Health and Environmental Research, Human Health and Assessments Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

INDOOR AIR POLLUTION FROM PORTABLE KEROSENE-FIRED SPACE HEATERS, WOOD-BURNING STOVES, AND WOOD-BURNING FURNACES

Gregory W. Traynor,

James R. Allen, Michael G. Apte, James F. Dillworth,
John R. Girman, Craig D. Hollowell, and James F. Koonce, Jr.
Building Ventilation and Indoor Air Quality Program
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Elevated levels of indoor air pollution can result from indoor use of combustion appliances. Rising energy prices have led to increased use of space heating appliances that use alternative fuels. Portable kerosene-fired space heaters, wood-burning stoves, and wood-burning furnaces, for example, while often economical sources of heat, can cause an increase in indoor pollutant levels.

Laboratory tests were conducted on four portable kerosene-fired heaters to identify the pollutants they emit and their emission rates. Results show that carbon dioxide, carbon monoxide, nitric oxide, nitrogen dioxide, and formaldehyde are emitted by both radiant and convective kerosene heaters and that radiant heaters also emit trace amounts of fine particles. For some pollutants, emissions per caloric value of fuel consumed increase with decreasing wick length. Operation of a radiant and convective heater in a 27-m^3 chamber with 0.4 air changes per hour for one hour results in CO_2 concentrations well above the U.S. occupational standard, and NO_2 concentrations well above California's short-term outdoor standard.

Emissions from two wood-burning stoves and two wood-burning furnaces were studied under uncontrolled "real-life" conditions. The results, although less generalizable than those from laboratory tests of kerosene-fired heaters, also show that levels of carbon monoxide, nitric oxide, nitrogen dioxide, and sulfur dioxide increase during stove operation, although the pollutant levels observed were generally below occupational and outdoor air quality standards.

INDOOR AIR POLLUTION FROM PORTABLE KEROSENE-FIRED SPACE HEATERS, WOOD-BURNING STOVES, AND WOOD-BURNING FURNACES

Introduction

Two areas of concern for both the scientific community and the general public are energy conservation and indoor air pollution.[1] Strategies designed to reduce energy costs are not always compatible with acceptable indoor air quality. For example, the increased use of alternative fuels aimed at reducing residential heating costs--such as the shift to unvented portable kerosene-fired space heaters, wood-burning stoves, and wood-burning furnaces--can have a detrimental effect on indoor air quality.

Other investigators have demonstrated that portable kerosene-fired space heaters emit nitric oxide (NO) and nitrogen dioxide (NO_2).[2] Wood-burning stoves have been found to emit carbon monoxide (CO) and particles (including benzo-a-pyrene) into the living space, particularly while loading and stoking the stove.[3] In our laboratory studies, we have investigated carbon dioxide (CO_2), CO, nitrogen oxides ($NO_x = NO + NO_2$), formaldehyde (HCHO), and fine particulate emissions, as well as oxygen consumption, for two types of portable kerosene-fired heaters, convective and radiant. In addition, we monitored CO, NO, NO_2, and SO_2 emissions from two wood-burning stoves and two wood-burning furnaces in occupied residences under actual living conditions.

Experimental Methods

For the laboratory tests of kerosene heaters and field monitoring of wood-burning appliances, we used two different mobile laboratories developed and constructed at the Lawrence Berkeley Laboratory.

Portable Kerosene-fired Heaters: Laboratory Tests

Tests on portable kerosene-fired heaters were conducted in a 27-m^3 environmental chamber, approximately the size of a kitchen or small bedroom. The chamber has an infiltration rate of 0.40 ± 0.03 air changes per hour (ach). The pollutant emission rates were quantified by means of a technique developed to determine pollutant emission rates from gas ranges.[4] The monitoring equipment used for gaseous and particulate emissions has been described elsewhere.[5]

Wood-burning Stoves and Wood-burning Furnaces: Field Tests

Field tests were conducted on wood-burning furnaces and wood-burning stoves in three occupied houses. House A is a 430-m^3 earth-sheltered structure with a wood-burning furnace in the basement and a wood-burning stove in the living room. Indoor air samples were drawn from the living room and master bedroom on the upper level and from the family room on the lower level. House B has an indoor volume of 460 m^3 and is heated by a wood-burning stove in the living room. Supplemental heat is provided by an oil-fired hot-water furnace exterior to the living space. Air samples were drawn from the kitchen and living room (upper floor) and from the master bedroom (ground floor). House C, with an indoor living space of 320 m^3, is heated by a forced-air wood-burning furnace in the basement. Indoor air samples were drawn from the living room, the family room, and a small bedroom--all on the main floor.

The occupants of House A and House C kept accurate logs recording each time the stove or furnace was fired. House B did not keep a log; however, the stove was the only combustion source in the house and all pollutant emissions were attributed to the wood-burning stove.

Air samples were taken from three indoor and one outdoor location on a rotating basis. Each location was monitored for 10 minutes. The first 6 minutes of data collected at each air-sampling site was discarded and the last 4 minutes of data were averaged. (More detailed information on the mobile laboratory used for these studies can be found elsewhere.[6])

Results

Our laboratory and field results show that the portable kerosene-fired space heaters and wood-burning appliances tested did elevate indoor air pollution levels.

Portable Kerosene-fired Heaters

All kerosene heaters tested, two convective and two radiant, were found to emit CO_2, CO, NO, NO_2, and HCHO; additionally, both radiant heaters and one convective heater emitted fine particles. The CO_2, CO, NO_2, and NO concentrations measured during the 1-hour operation of a portable convective and radiant kerosene heater are shown in Figures 1 and 2, respectively. In both cases, CO_2 levels reached twice the 8-hour U.S. occupational standard of 5,000 ppm.[7] NO_2 levels from both types of heaters did not exceed the occupational standard of 5.0 ppm[7] but did exceed the California short-term (1-hour) standard of 0.25 ppm[8]--by a factor of seven for the convective heater and by a factor of two for the radiant model. Although the NO_x emissions from the convective heater were greater than those from the radiant heater, the radiant heaters emitted more CO. The only two pollutants measured that exceeded occupational or outdoor air quality standards were CO_2 and NO_2.

Table I summarizes the pollutant emission rates from 12 tests on the four different heaters. The CO_2 production and O_2 consumption were relatively constant for both convective and radiant heaters. As is evident, NO_x emissions were greater for convective heaters while CO, HCHO, and fine-particle emissions were greater for radiant heaters. The difference is probably due to the hotter flame in convective heaters. The NO_x results are slightly below those of Yamanaka et al.[2] When results from the two studies are converted to cm^3 per kJ of NO_x emitted (standardized for 25 ^oC), the differences are minor: 0.027 and 0.026 cm^3/kJ of NO_x from our convective heater tests and 0.0034 and 0.0043 cm^3/kJ for radiant heater tests, in contrast to Yamanaka's findings of 0.027 to 0.035 cm^3/kJ for convective heaters and 0.0044 to 0.0065 cm^3/kJ for radiant heaters. Average HCHO concentrations measured in the chamber for one hour after the heaters were turned off were 12.5 ppb for the new convective heater under full-wick conditions (tests #1-1 to #1-4) and 66.3 ppb for the new radiant heater under full-wick conditions (tests #3-1 and #3-2). For the new convective heater, under the same full-wick conditions, the average increase in fine particulate levels was below detection (< 0.2 $\mu g/m^3$) during the 1-hour period after the heater was turned off, but for the new radiant heater the increase averaged 4.0 $\mu g/m^3$ above background levels, a value still well below occupational or outdoor air quality standards.

To differentiate the emissions during the first 10 minutes of operation from those associated with "steady-state" operation, we conducted emission rate tests with and without a 10-minute warm-up period. In general, there was no significant difference in emission rates with and without a warm-up period. The only exception was with the 5-year-old convective heater which emitted 440 μg of fine particles upon ignition (visually seen as smoke)--a burst that did not occur in the other heaters tested.

Manufacturers' information specifies a procedure for adjusting the wicks to their optimum length. For our tests, the maximum wick extension (full-wick) produced the best burning conditions; however, because the wicks are adjustable and can also shorten with time, we conducted additional tests to determine the effects of reducing the wick length. On the new convective heater, the wick was reduced until the flame was approximately one-half its original length. As evident on Table I (test #1-5), the fuel-consumption rate was thereby reduced whereas the CO and HCHO emission rates increased by factors of 8 and 4, respectively. For the new radiant heater, the wick was reduced by adjusting the wick control knob to one-half its full setting slightly decreasing the fuel-consumption rate. The results (tests #3-3 and #3-4) show that CO emissions from this heater also increased with decreased fuel consumption. HCHO and fine particulate emissions increased slightly but did not appear to be as significant as the CO emissions.

The emission rates presented in Table I, combined with specific heater-use patterns, building characteristics (such as air-exchange rate and building volume)--and, possibly, other parameters--can be entered into an indoor air quality model[9] to determine indoor pollution levels and profiles for other structures where these appliances are used.

Wood-burning Stoves and Wood-burning Furnaces

Houses with wood-burning stoves and wood-burning furnaces showed elevated levels of CO, NO, NO_2, and SO_2 during the period these appliances were operated. (Particulate concentrations were not measured.) Figure 3 shows the kitchen, living room, and bedroom concentrations of NO in House B over a 6-day period when the stove was used heavily. The NO emitted by the stove appears to leak slowly from the appliance rather than episodically, e.g., during stoking and reloading.

In House C, on the other hand, the NO_2 levels measured during the operation of the wood-burning furnace did appear to be episodic, as depicted in Figure 4. This behavior may be due to the initial spillage of pollutants from the furnace during its warm-up period, i.e., before a sufficient draft was created in the flue to exhaust all of the pollutants. That the outdoor peak coincided with the indoor peak is probably because the plume from the furnace chimney increased the pollutant levels near the outdoor probe location.

Table II summarizes the indoor and outdoor pollutant peaks during operation of the wood-burning stove or furnace in Houses A, B, and C. In general, the pollutant levels observed in all three houses were below occupational and outdoor air quality standards. Of the four appliances tested, the wood-burning stove in House A contributed the least to indoor pollution levels. In the case of the reactive pollutants, NO_2 and SO_2, we would expect indoor levels to be about 40%[10] and 50%[11], respectively, of those observed outside. In other words, in those instances when indoor and outdoor NO_2 and SO_2 values are comparable, it is the indoor pollutants generated by the wood-burning appliance that account for their apparent similarity.

Comparisons of indoor pollution levels from wood-burning stoves in Houses A and B and wood-burning furnaces in Houses A and C show that the magnitude of pollutant emissions from these appliances vary--for reasons not yet identified. In addition, the major component of gaseous pollutants also varies; for example, the dominant pollutant from the wood-burning stove in House B was NO; from the wood-burning furnace in House A, CO; and from the wood-burning furnace in House C, NO_2. By comparison, Moschandreas et al. observed a peak 1-hour CO concentration of 6 ppm during the stoking of a wood stove as well as an increase in indoor particulate levels, although they state that "No other gaseous pollutant monitored [including NO, NO_2 and SO_2] in the study showed a strong association with woodburning indoors."[3] Obviously, more research needs to be done in this area.

Conclusions

The indoor use of unvented portable kerosene-fired space heaters can cause an elevation in the levels of many pollutants. The U.S. occupational standard for CO_2 and the California short-term standard for NO_2 were exceeded in our environmental chamber when such appliances were used and could be similarly exceeded in larger environments, especially if the appliance operating times are longer than one hour. The data presented can be used with an indoor air quality model to estimate indoor pollution levels in other structures. Such estimates should be combined with data on health risks from pollutants in order to establish the potential hazard of using kerosene heaters indoors. When using these appliances in small rooms, increased ventilation or other pollution-control strategies should be considered.

Emissions from wood-burning stoves and wood-burning furnaces appear to vary considerably not only in terms of the mix of pollutants emitted but also in their total contribution to indoor air pollution. The limited data presented here point out the need to study wood-burning appliances more systematically, first to identify those that are high polluters, then to determine the path through which pollutants enter the living space and, finally, to devise appropriate control strategies. Unlike unvented appliances, such devices might be modified to reduce pollutant emissions by improving the flue system. For example, a mechanical fan might be installed in the flue system to automatically increase the draft during the initial warm-up period (for a wood-burning furnace) or during loading and stoking (for a wood-burning stove).

Acknowledgments

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division, and by the Director, Office of Energy Research, Office of Health and Environmental Research, Human Health and Assessments Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

References

1. "Indoor Pollutants," National Academy of Sciences, Washington, D.C., 1981.

2. S. Yamanaka, H. Hirose and S. Takada, "Nitrogen oxide emissions from domestic kerosene-fired and gas-fired appliances," Atmospheric Environment, 13: 407 (1979).

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

4. G. W. Traynor, D. W. Anthon and C. D. Hollowell, "Technique for determining pollutant emissions from a gas-fired range," LBL-9522, Lawrence Berkeley Laboratory, Berkeley, CA 94720 (1981); accepted for publication in Atmospheric Environment.

5. J. R. Girman, M. G. Apte, G. W. Traynor and C. D. Hollowell, "Pollutant emission rates from indoor combustion appliances and sidestream cigarette smoke," LBL-12562, Lawrence Berkeley Laboratory, Berkeley, CA 94720 (1982); submitted to Environment International.

6. C. D. Hollowell, R. A. Young, J. V. Berk and S. R. Brown, "Energy-conserving retrofits and indoor air quality in residential housing," Presented at the ASHRAE Symposium HO-82-6, Ventilation and Indoor Air Quality, Houston, TX, January 24-28, 1982; to be published in ASHRAE Transactions.

7. U.S. Federal Register, Vol. 44, No. 29, pp. 8853-8856 (February 9, 1979).

8. State of California, California Administrative Code, Title 17, Subchapter 1.5, Section 70100, 1977.

9. G. W. Traynor, M. G. Apte, J. F. Dillworth, C. D. Hollowell and E. M. Sterling, "The effects of ventilation on residential air pollution due to emissions from a gas-fired range," LBL-12563, Lawrence Berkeley Laboratory, Berkeley, CA 94720 (1982); submitted to Environment International.

10. Lawrence Berkeley Laboratory, unpublished data from forty-four homes with no unvented combustion appliances show the average indoor/outdoor NO_2 ratio to be 0.39 ± 0.27.

11. I. Anderson, "Relationships between outdoor and indoor air pollution," Atmospheric Environment, 6: 275-278 (1972).

TABLE I. POLLUTANT EMISSION RATES FROM PORTABLE KEROSENE-FIRED SPACE HEATERS

Heater and Test #	Test Description	Fuel Consumption[a] (kJ/hr)	Emission Rates						Volumetric NO_2/NO Ratio
			CO (μg/kJ)	CO_2 (μg/kJ)	N (of NO_x) (μg/kJ)	HCHO (μg/kJ)	O_2 (μg/kJ)	Fine Particles[b] (μg/kJ)	
Convective (New)									
1-1	Fired in chamber	7830	14.5	70,100	15.3	0.01	-77,200	<0.004	0.39
1-2	Fired in chamber	7980	10.3	72,500	15.6	0.08	-78,900	<0.004	0.33
1-3	10-min warm-up[c]	7850	9.1	70,700	15.5	0.14	-73,800	<0.004	0.35
1-4	10-min warm-up	7840	9.1	70,400	15.5	0.18	-78,000	<0.004	0.31
1-5	Reduced wick (10-min warm-up)	4230	84.9	78,000	16.0	0.42	-82,800	<0.004	0.80
Convective (5 yr old)									
2-1	Fired in chamber	5480	115.1	69,000	15.3	1.22	-79,500	d	1.84
2-2	10-min warm-up	5780	110.5	63,600	14.2	0.98	-80,900	0.006	1.59
Radiant (New)									
3-1	Fired in chamber	8180	60.2	70,300	2.2	0.63	-76,700	0.019	2.03
3-2	10-min warm-up	8250	71.7	68,500	1.8	0.49	-79,600	0.022	2.27
3-3	Reduced wick (10-min warm-up)	7180	141.3	70,600	1.6	0.80	-81,800	0.031	11.86
3-4	Reduced wick (10-min warm-up)	7650	91.7	71,900	1.7	0.58	-80,900	0.022	4.98
Radiant (1 yr old)									
4-1	10-min warm-up	6640	54.0	66,200	2.5	0.10	-78,000	0.019	1.68

[a] 1.000 kJ/hr = 0.948 Btu/hr; heat content of kerosene = 43.5 kJ/g.

[b] Mass of particles from 0.005 to 0.4 μm in diameter, analyzed by electrical mobility detector, assuming particulate density of 2.0 g/cm^3.

[c] All warm-ups were conducted outside the chamber to avoid initial transient emissions.

[d] 440 μg emitted at ignition; heater ignited with butane lighter.

TABLE II. INDOOR AND OUTDOOR POLLUTANT PEAKS DURING WOOD-BURNING STOVE/WOOD-BURNING FURNACE OPERATION

Appliance and House Code	Average Air Exchange Rate (hr^{-1})	House Volume (m^3)	Number of Appliance Uses	Pollutant Peaks[a]											
				CO			NO			NO_2			SO_2		
				Indoor Mean (ppm)	Indoor Range (ppm)	Outdoor Mean (ppm)	Indoor Mean (ppb)	Indoor Range (ppb)	Outdoor Mean (ppb)	Indoor Mean (ppb)	Indoor Range (ppb)	Outdoor Mean (ppb)	Indoor Mean (ppb)	Indoor Range (ppb)	Outdoor Mean (ppb)
Wood Stove															
A	0.30 ± 0.04 (3)[b]	430	10	0.7 ±0.2	0.4- 1.1	0.3 ±0.3	10.2 ±6.9	3.1- 21.4	2.4 ±2.8	4.2 ±0.9	3.0- 5.5	3.0 ±1.9	19.3 ±8.5	5.5- 36.3	7.0 ±5.6
B[c]	0.08 ± 0.00 (2)	460	7	1.0 ±0.4	0.5- 1.6	0.4 ±0.2	78.1 ±27.8	45.1- 114.6	3.0 ±7.4	25.4 ±6.0	17.0- 35.7	22.0 ±6.5	64.0 ±12.7	48.9- 85.7	61.9 ±11.1
Wood Furnace															
A	0.30 ± 0.04 (3)	430	3	8.6 ±1.7	6.9- 10.3	0.1 ±0.0	28.1 ±4.2	23.9- 32.4	1.1 ±0.5	3.1 ±1.4	1.8- 4.6	3.4 ±4.6	48.2 ±26.3	29.0- 78.1	19.1 ±20.3
C	0.40 ± 0.13 (4)	320	2	2.6 ±1.8	1.3- 3.9	0.4 ±0.1	136.4 ±125.2	47.9- 224.9	3.4 ±1.6	227.4 ±130.0	135.5- 319.3	20.8 ±4.9	No Data	No Data	No Data

[a]Average of living room, bedroom, and kitchen or family room.

[b]Figures in parentheses represent the number of air exchange rate tests conducted.

[c]Pollutant levels sustained over long periods of time, rather than episodic.

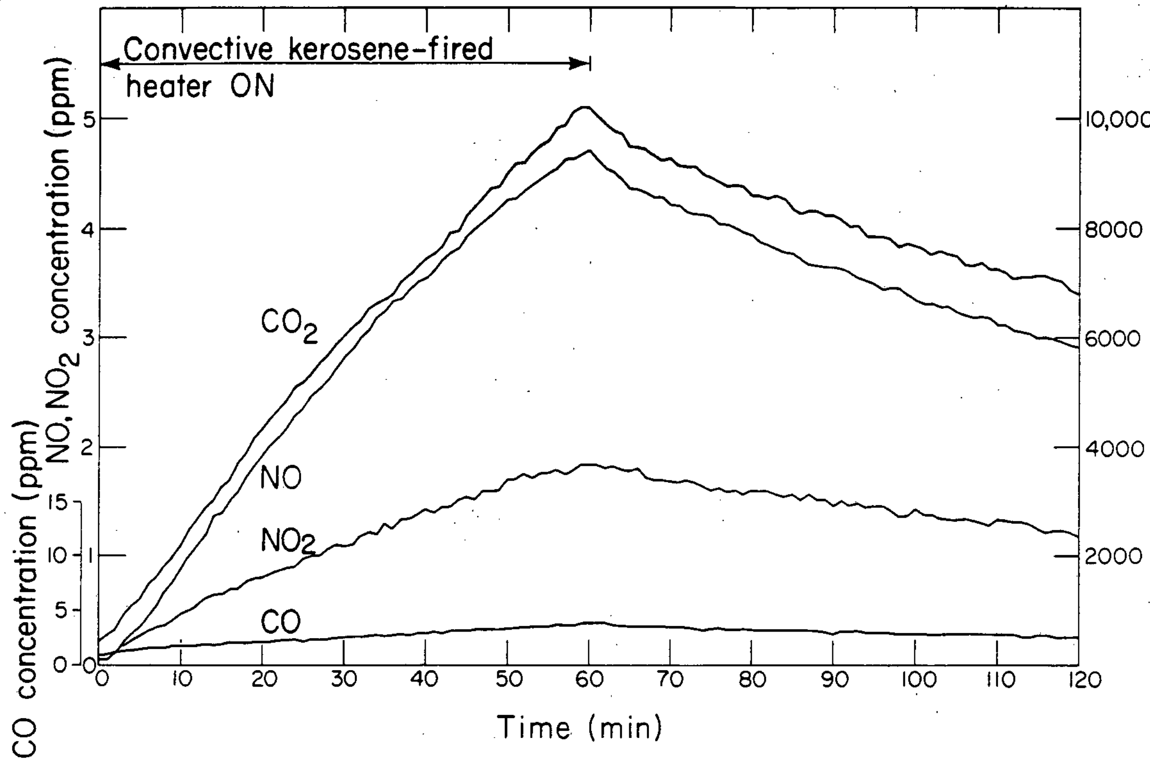


Figure 1. CO, CO_2, NO, and NO_2 concentrations measured during operation of a convective portable kerosene-fired space heater in a well-mixed 27-m^3 chamber. Fuel consumption was 7830 kJ/hr (7430 Btu/hr) and the air exchange rate was 0.39 air changes per hour; test #1-1.

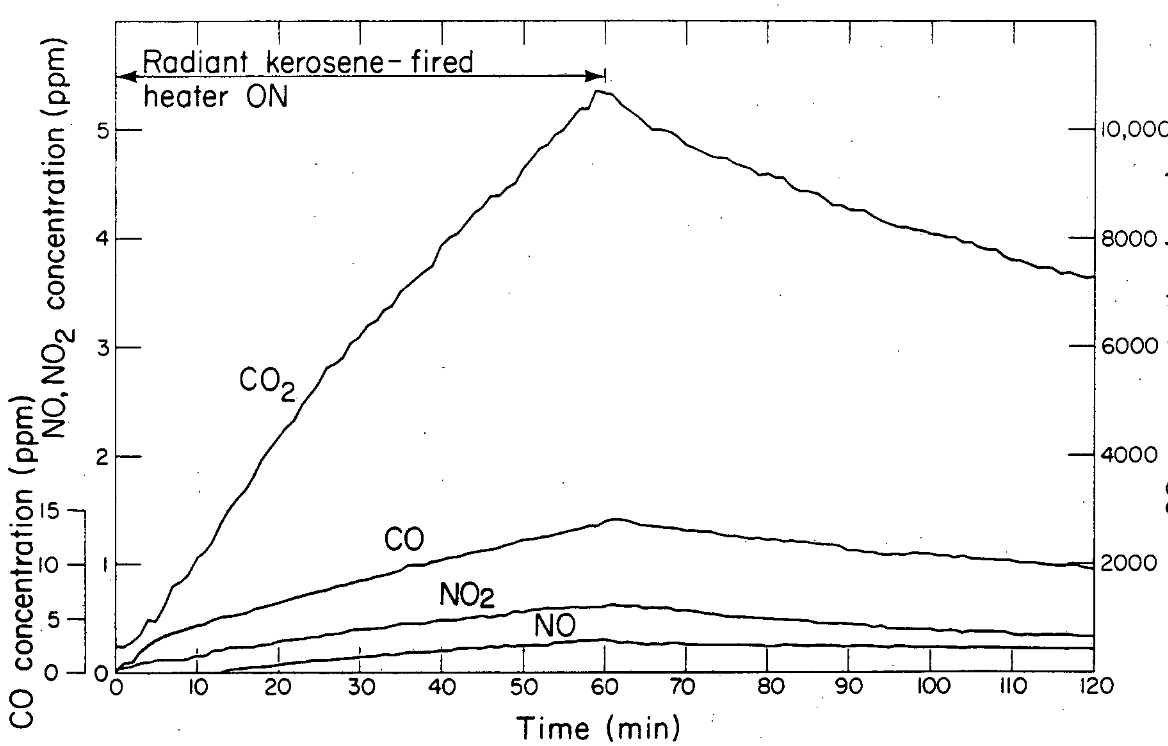


Figure 2. CO, CO_2, NO, and NO_2 concentrations during operation of a radiant portable kerosene-fired space heater in a well-mixed 27-m^3 chamber. Fuel consumption was 8180 kJ/hr (7760 Btu/hr) and the air exchange rate was 0.40 air changes per hour; test #3-1.

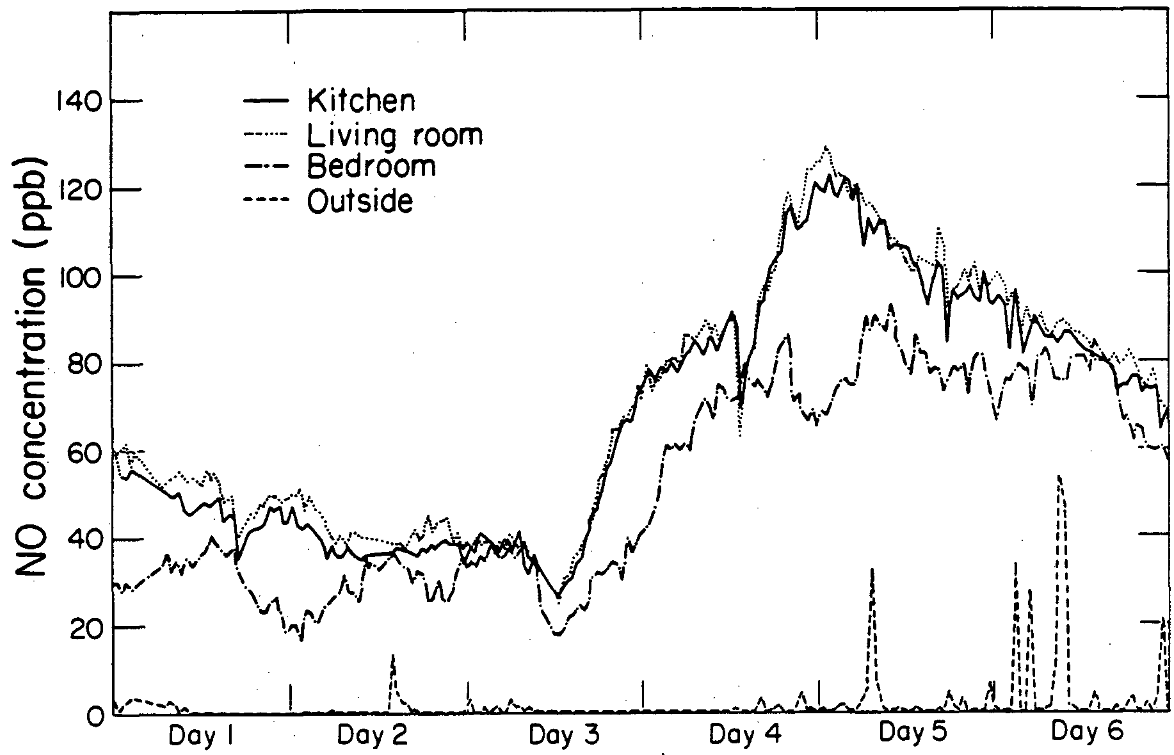


Figure 3. NO concentrations in House B (vol = 460 m^3) during operation of wood-burning stove. The wood stove was the only indoor combustion pollutant source in House B. The air exchange rate was approximately 0.08 air changes per hour.

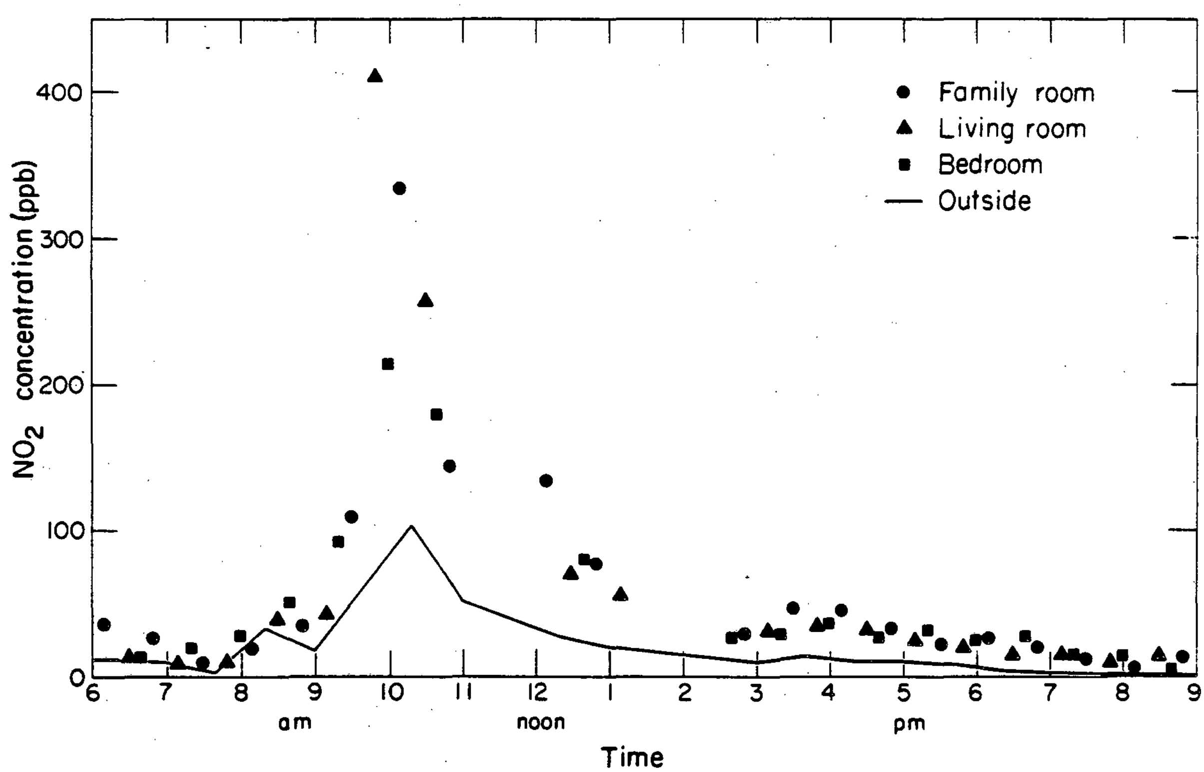


Figure 4. NO_2 concentrations in House C (vol = 320 m^3) just before and during the operation of a wood-burning furnace. The air exchange rate was 0.40 ± 0.13 air changes per hour.