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Abstract

Indoor use of unvented combustion appliances is known to cause an increase in indoor air pollutant levels. We conducted laboratory tests on radiant and convective portable kerosene-fired space heaters to identify the pollutants they emit and to determine their emission rates. This paper summarizes laboratory-derived CO and NO_2 emission rates from unvented portable kerosene-fired space heaters and shows the effect of wick height and fuel consumption rate on CO and NO_2 emissions. Pollutant concentration profiles resulting from the use of kerosene heaters in a 27-m^3 environmental chamber and a 240-m^3 house are presented. When such heaters are operated for one hour in a 27-m^3 chamber with 0.4 air changes per hour, the resultant CO_2 concentrations are well above the U.S. occupational standard, and NO_2 concentrations are well above California's short-term outdoor standard. Further data on parameters such as heater usage patterns and air exchange rates are needed to determine the actual pollutant exposure that kerosene heater users experience.

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Introduction

The Building Ventilation and Indoor Air Quality Program at the Lawrence Berkeley Laboratory has studied many issues in indoor air pollution -- those related to formaldehyde, radon, and combustion products are primary among them. We have found that many factors determine the levels of indoor air pollution caused by the use of unvented combustion appliances such as portable kerosene-fired space heaters. One important factor is the pollutant source strength profile of the appliance, which is a combination of the appliance's use pattern and its pollutant emission rate. Other important factors are the volume of the heated space, the air exchange rate, the reactivity of pollutants emitted, and the use of local (or spot) ventilation devices (e.g., hood and fan built above a gas range). Figure 1 shows the relationship among the various interrelated factors that influence indoor air pollution levels.

Our past research has been directed at determining the pollutant emission rates of various residential combustion appliances, largely because many of the other factors that influence indoor air pollution levels are occupant- or building-specific parameters. We observe that appliance use patterns are a combination of occupant preferences and the building's heating requirements.

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At present little knowledge exists concerning the exposure to pollutants experienced by people who use kerosene-fired space heaters. However, we can and have determined the emission characteristics of kerosene heaters both per unit of fuel consumed and per unit of time. We have previously reported the emission rates for four kerosene-fired space heaters operated under various conditions[1] and the techniques and instrumentation employed in our studies.[2,3] This paper summarizes the laboratory emission rate measurements of CO and NO_2 for a white-flame convective heater and a blue-flame radiant heater. Pollutant concentration profiles during the use of these heaters in 27-m^3 environmental chamber and 240-m^3 house are also presented.

Laboratory Results

The concentrations of CO_2, CO, NO_2, and NO emitted from a white-flame convective heater are shown in Figure 2 and those from a blue-flame radiant heater are shown in Figure 3; in both cases, heaters were operated under "optimal" wick conditions as defined by the manufacturer's instructions. The heaters were operated for one hour in a 27-m^3 environmental chamber with approximately 0.4 air changes per hour. For both heater types, CO_2 levels reached twice the 8-hour U.S. occupational standard of 5,000 ppm.[4] Operation of neither heater caused NO_2 levels to exceed the U.S. occupational standard of 5.0 ppm,[4] but the California short-term (1-hour) outdoor standard of 0.25 ppm[5] was exceeded -- by a factor of seven for the convective heater and by a factor of two for the radiant model. CO levels from the convective heater were very low whereas CO levels from the radiant heater exceeded the Environmental Protection Agency's outdoor 8-hour standard of 9 ppm but were below its 1-hour standard of 35 ppm.[6] (Bear in mind that the applicability of outdoor or occupational air quality standards to residential environments has not been established.)

The white-flame convective heater because of its hotter flame and more-complete combustion emits little CO compared to the blue-flame radiant heater. On the other hand, a hotter flame produces more NO and NO_2 emissions. Because of this, it is difficult to reduce NO_x emissions and CO emissions simultaneously. Thus the blue-flame radiant heaters emit less NO_x than the white-flame convective heaters. Figures 2 and 3 show that the CO_2 levels were the same for both the radiant and convective heaters. Since CO_2 is a product of complete kerosene combustion, the CO_2 emission rates are constant regardless of type of heater.

During full-wick tests, the average chamber temperature increases were 11.4 °C (20 °F) for the convective heater tests and 10.7 °C (19 °F) for the radiant heater tests during the one-hour burn time. At no time did the temperature in the chamber exceed 26 °C (79 °F).

Although a given kerosene heater is manufactured with a single heat output rating, one might reduce the wick in order to reduce the heat output. In general, reducing the wick height reduces the fuel consumption rate and would be expected to reduce the pollutant source strength proportionally. This is not true for CO, as is evident from the data presented in Table 1. When the wick height of the convective heater was reduced to roughly half its original height, the CO emission rate increased by a factor of 8, counteracting the reduction in fuel consumption. The source strength, the actual amount of pollution emitted by the heater per hour, increased by a factor of roughly 4. When the wick height on the radiant heater was reduced to cause a reduction of the fuel consumption rate of approximately 87% of its "optimal" level, the CO source strength doubled. In other words, if a user adjusts the wick height to adjust the heat output on the kerosene heater, he or she may thereby reduce source strengths of some pollutants but not that of CO. The same can be said of convective-heater NO_2 emissions as confirmed by the data presented in Table 2.

Field Results

Field tests were conducted to check the validity of using laboratory-derived emission rates as a basis for determining indoor pollutant concentrations. Both the white-flame convective heater and the blue-flame radiant heater were operated in the living room of a 240-m^3 unoccupied, partially furnished, three-bedroom house that had been extensively retrofitted for energy efficiency. Because its air-exchange rate was much lower than is typical for the U.S. housing stock, all windows were open one to two centimeters to artificially increase the air flow through the house during the tests. The kitchen and living room of the house are both part of a larger room separated by a partial wall. The bedroom referred to in this paper is located at the end of a hallway extending from the living room.

Figures 4 and 5 show the pollutant, temperature, and dew point profiles for three locations in the house and the outdoors during tests of the convective and radiant heaters. The air exchange rates and net indoor NO_2 reactivity rates were 0.55 h^{-1} and 0.18 h^{-1}, respectively, for the convective heater test (Fig. 4) and 0.64 h^{-1} and 0.29 h^{-1}, respectively, for the radiant heater test (Fig. 5). The net indoor NO_2 reactivity rate is the net rate of indoor NO_2 removal processes, either chemical or physical, other than air flow. The fuel consumption rates for the convective and radiant heater tests were 9000 kJ/h (8530 Btu/h) and 9330 kJ/h (8840 Btu/h), respectively. During the test of the convective heater, the average indoor temperature rose 4.1 °C (7.4 °F), and the indoor/outdoor temperature difference at the heater "off" time was 10.4 °C (18.7 °F). During the test of the radiant heater, the average indoor temperature rose 2.7 °C (4.9 °F) and the indoor/outdoor temperature difference at the heater "off" time was 10.2 °C (18.4 °F).

In both tests (Fig. 4 and 5) the peak CO_2 concentrations averaged over the whole house (i.e., the average of the living room, bedroom and kitchen concentrations) were slightly above half the U.S. 8-hour occupational guideline of 5000 ppm,[4] 3100 ppm for the convective test and 2900 ppm for the radiant test. In neither test did the whole-house peak CO concentration reach the EPA 8-hour guideline of 9 ppm.[6] The calculated CO emission rate was less than 10 μg/kJ for the convective heater and was 120 μg/kJ for the radiant heater. The whole-house peak NO_2 concentrations were 0.25 ppm for the convective test and 0.11 ppm for the radiant tests. The EPA 1-year standard for NO_2--0.05 ppm[6]--was exceeded during both tests, although neither test exceeded the California 1-hour NO_2 standard of 0.25 ppm.[5] The calculated NO_2 emission rate was 9.3 μg/kJ for the convective test and 4.7 μg/kJ for the radiant test. The CO and NO_2 emission rates for these tests were consistent with those previously measured in the laboratory and reported in Tables 1 and 2.[1]

Summary

This paper showed the effect of wick height and fuel consumption rate on CO and NO_2 emissions from a white-flame convective heater and a blue-flame radiant heater. Pollutant concentration profiles resulting from the use of kerosene heaters in a 27-m^3 environmental chamber and a 240-m^3 house were presented. If kerosene heaters are used in spaces with small volumes and/or low air exchange rates, indoor pollution concentrations can exceed state and/or federal outdoor or occupational air quality standards. Further data on parameters such as usage patterns of heaters and air exchange rates are needed to determine the actual pollutant exposure that kerosene heater users experience.

References

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2. G.W. Traynor, D.W. Anthon, and C.D. Hollowell. 1982. Technique for determining pollutant emissions from a gas-fired range. Atmospheric Environment, 16, 12, 2979.

3. J.R. Girman, J.R. Allen, M.G. Apte, V.M. Martin, and G.W. Traynor. 1982. Pollutant emission rates from unvented gas-fired space heaters: a laboratory study. Report # LBL-14502, Lawrence Berkeley Laboratory, Berkeley, CA 94720.

4. U.S. Government, Code of Federal Regulations, Title 29, Section 1910.1000, 1979.

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

6. U.S. Government, Code of Federal Regulations, Title 40, Section 50.8, 1975.

Table 1. The Effect of Wick Height on CO Emissions in White-Flame Convective and Blue-Flame Radiant Kerosene-Fired Space Heaters.

Heater type and wick level	Number of tests	Fuel consumption rate (kJ/h)	CO emission rate (μg/kJ)	CO source strength (μg/h)
Convective (new)				
"optimal" wick height	4	7880 ± 70	10.8 ± 2.6	85,000 ± 21,000
reduced wick height	1	4230	84.9	360,000
Radiant (new)				
"optimal" wick height	2	8220 ± 50	66.0 ± 8.1	540,000 ± 70,000
reduced wick height 1	1	7650	91.7	700,000
height 2	1	7180	141.3	1,010,000

Table 2. The Effect of Wick Height on NO_2 Emissions in White-Flame Convective and Blue-Flame Radiant Kerosene-Fired Space Heaters.

Heater type and wick level	Number of tests	Fuel consumption rate (kJ/h)	NO_2 emission rate (μg/kJ)	NO_2 source strength (μg/h)
Convective (new)				
"optimal" wick height	4	7880 ± 70	12.9 ± 0.8	102,000 ± 7,000
reduced wick height	1	4230	25.0	106,000
Radiant (new)				
"optimal" wick height	2	8220 ± 50	4.7 ± 0.8	39,000 ± 7,000
reduced wick height 1	1	7650	5.0	38,000
height 2	1	7180	5.0	36,000

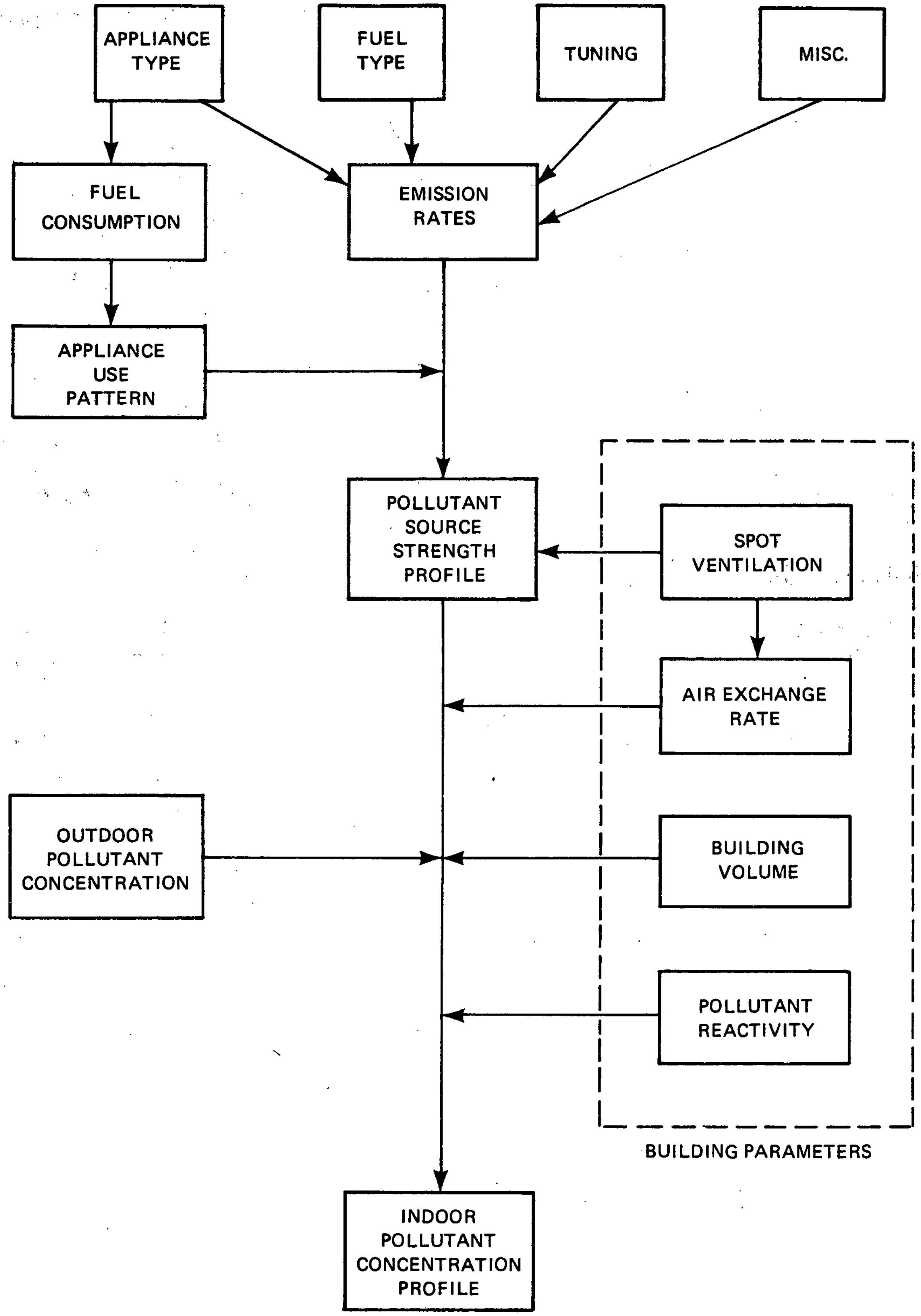

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Figure 1. Flow chart of interrelated factors that determine indoor pollutant concentrations from combustion appliances.

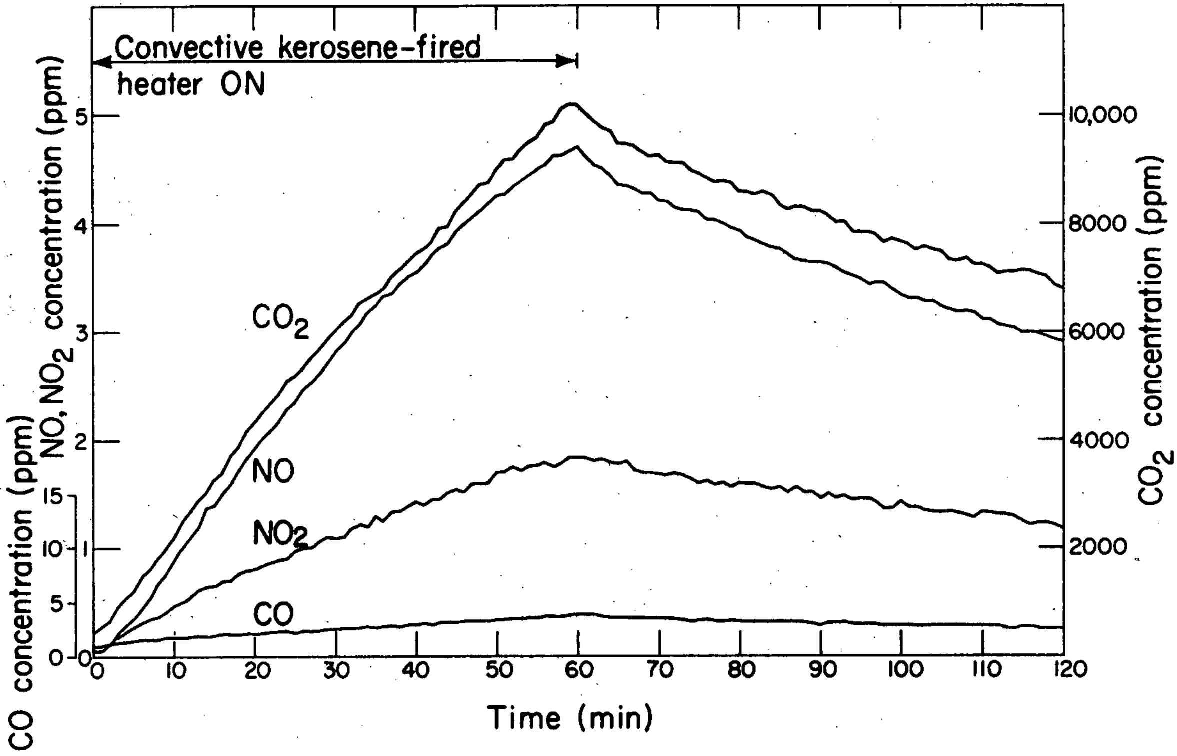

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Figure 2. Profiles of CO, CO_2, NO, and NO_2 measured during operation of a portable, white-flame, convective kerosene-fired space heater in a 27-m^3 chamber with well-mixed air. Fuel consumption was 7830 kJ/h (7430 Btu/h) and the air exchange rate was 0.39 air changes per hour.

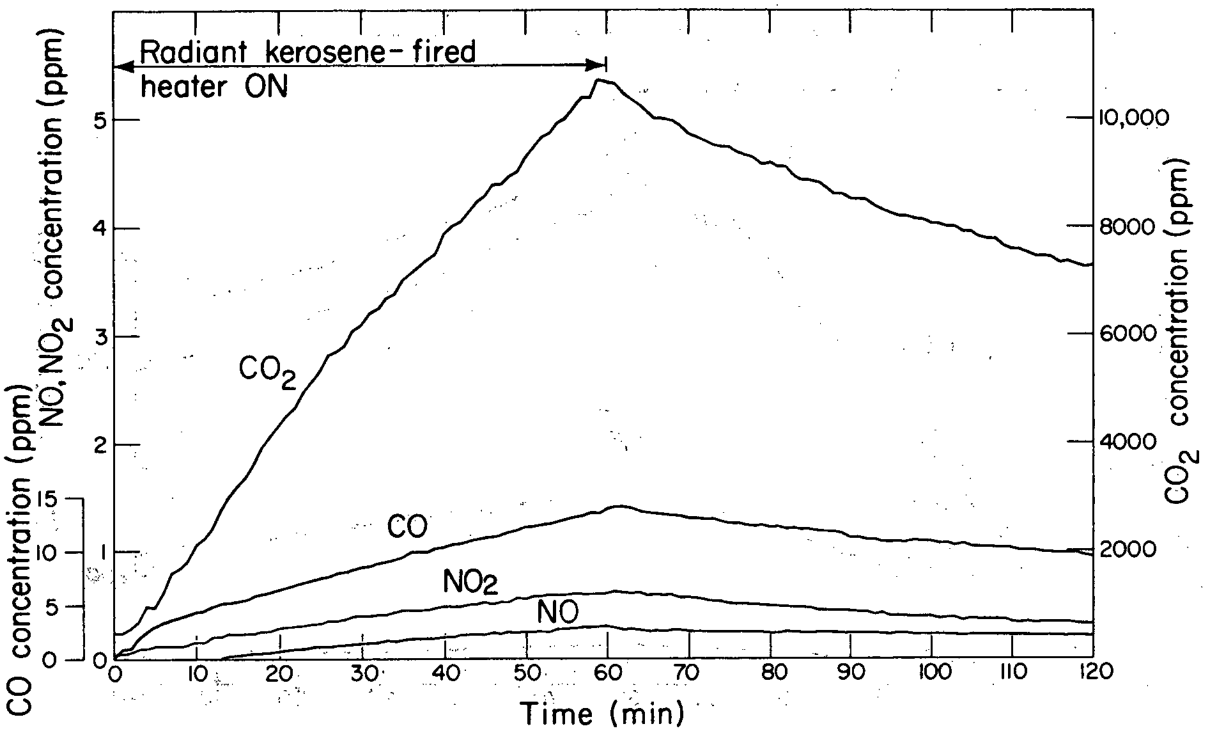

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Figure 3. Profiles of CO, CO_2, NO, and NO_2 measured during operation of a portable, blue-flame, radiant kerosene-fired space heater in a 27-m^3 chamber with well-mixed air. Fuel consumption was 8180 kJ/h (7760 Btu/h) and the air exchange rate was 0.40 air changes per hour.

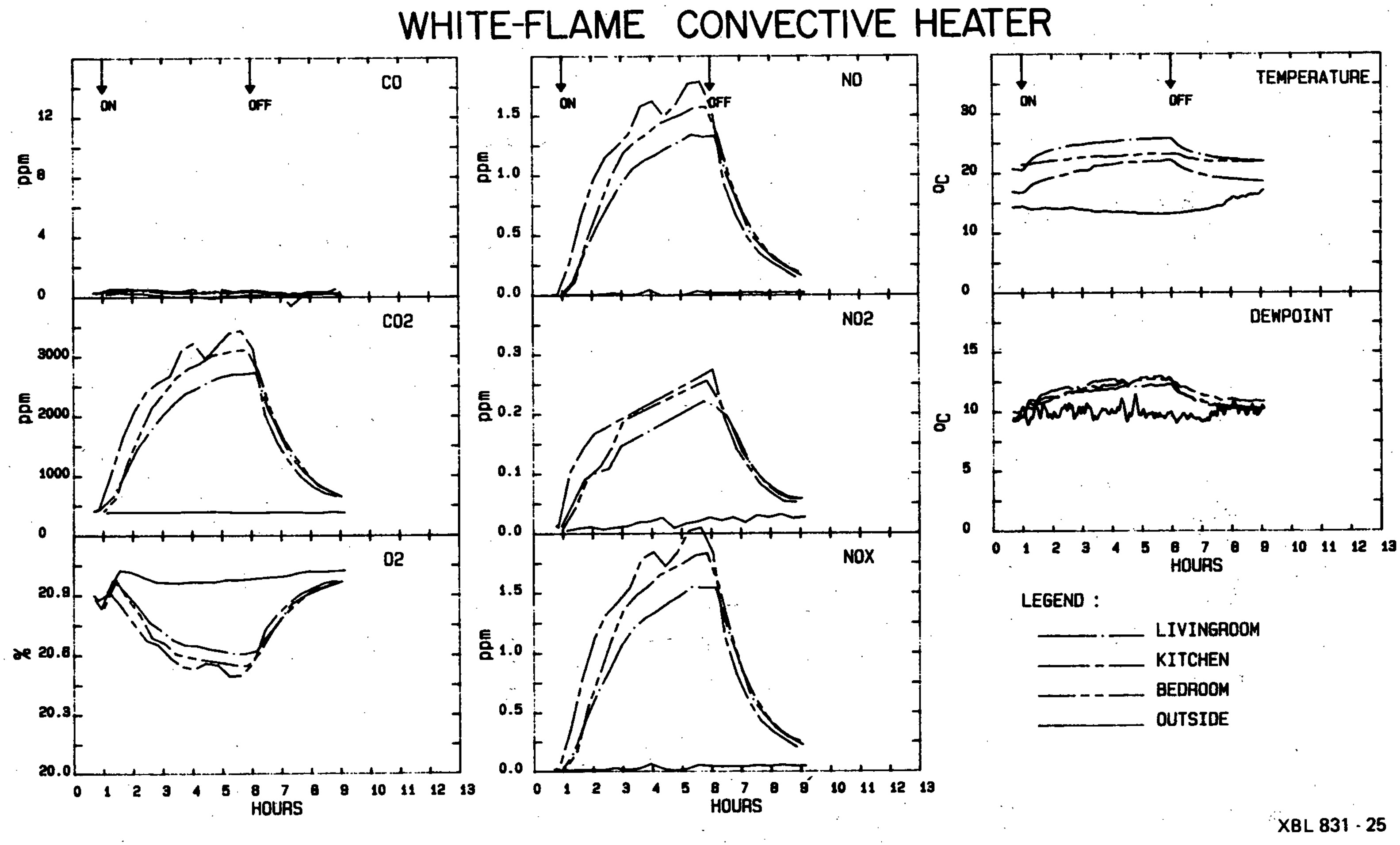

Figure 4. Profiles of pollutant concentrations, temperatures, and dew points measured during the operation of a portable, white-flame, convective kerosene-fired space heater in the living room of a 240-m^3 house. Fuel consumption rate was 9000 kJ/h (8530 Btu/h) and the air exchange rate was 0.55 air changes per hour.

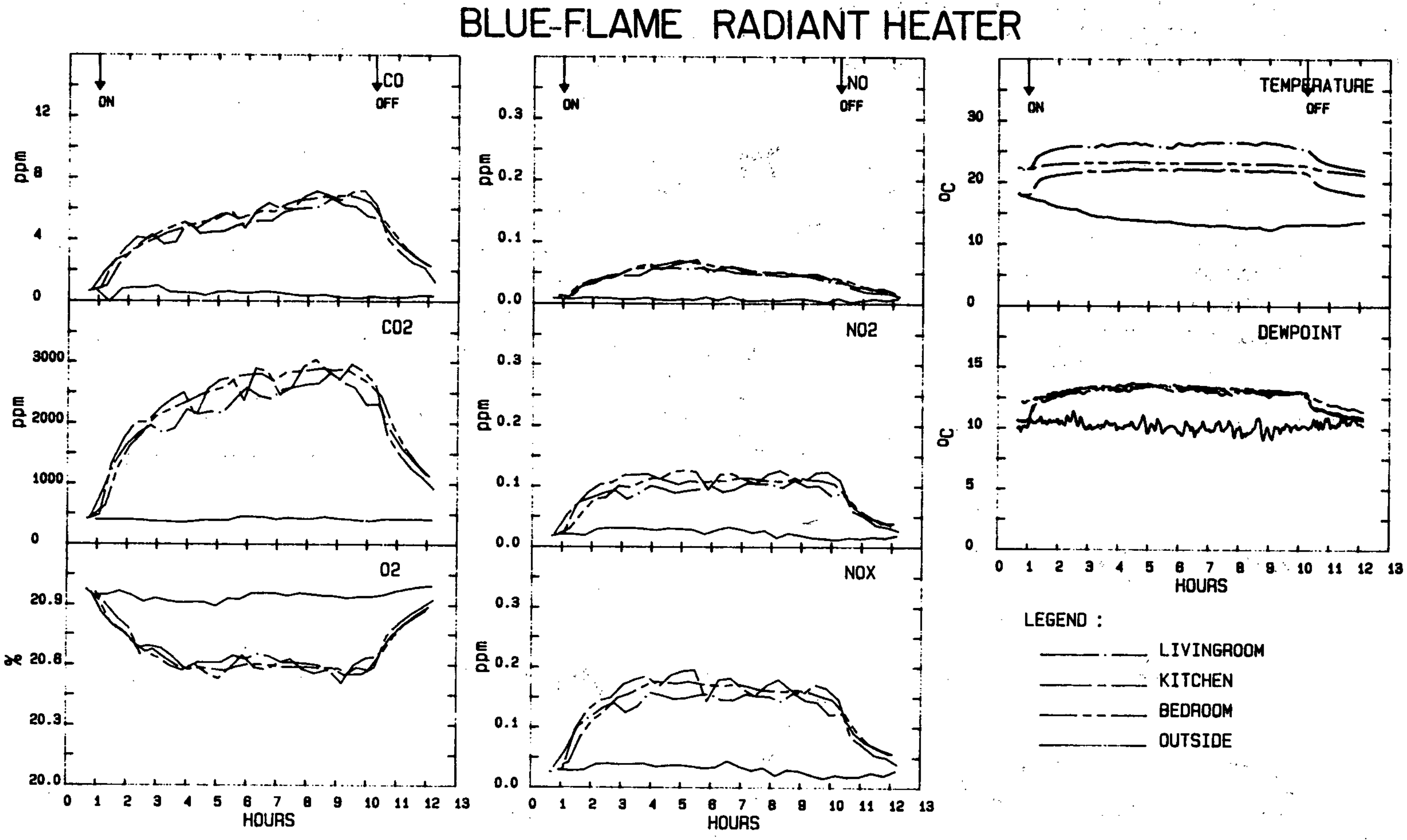

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Figure 5. Profiles of pollutant concentrations, temperatures, and dew points measured during the operation of a portable, blue-flame, radiant kerosene-fired space heater in the living room of a 240-m^3 house. Fuel consumption rate was 9330 kJ/h (8840 Btu/h) and the air exchange rate was 0.64 air changes per hour.

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