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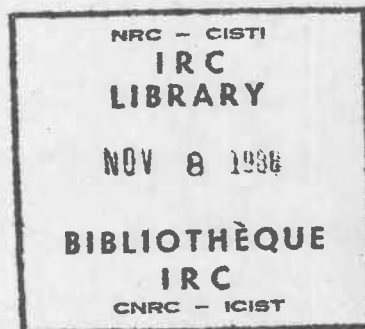
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## ***Measurement of Combustion Products from Kerosene Space Heaters in a Two-Story House***

by G.T. Tamura

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## RÉSUMÉ

L'utilisation de poêles au kérosène non ventilés peut augmenter considérablement les niveaux de produits de combustion dans les habitations. Afin de déterminer l'importance de ce phénomène, on a réalisé des essais dans une maison de contrôle de deux étages équipée de poêles de types rayonnant et convectif. On a déterminé les taux d'émission de CO, de CO<sub>2</sub>, de NO et de NO<sub>2</sub>. De plus, chaque appareil a été placé, à tour de rôle, dans le séjour, la chambre à coucher et le sous-sol, et les niveaux de produits de combustion ont été mesurés dans chaque pièce. Les valeurs du facteur de mélange à appliquer à l'équation générale de ventilation aux fins de l'estimation des niveaux de contaminants de l'air ont été déterminées à partir des résultats des essais.

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# MEASUREMENT OF COMBUSTION PRODUCTS FROM KEROSENE SPACE HEATERS IN A TWO-STORY HOUSE

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## ABSTRACT

Use of unvented kerosene space heaters can increase significantly the indoor levels of combustion products. To determine the amount of increase, tests have been conducted in a two-story test house using radiant and convective type space heaters. Emission rates of CO, CO<sub>2</sub>, NO, and NO<sub>2</sub> were determined. As well, each heater was placed, in turn, in the living room, bedroom, and basement, and the levels of combustion products were measured in each room. Values of mixing factor to be applied to the general ventilation equation for estimating air contaminant levels were determined from the test results.

## INTRODUCTION

Kerosene space heaters are usually unvented, allowing combustion products to permeate the living spaces. This type of heater has been of concern for some time because of possible unacceptable indoor levels of contamination and adverse health effects.

To investigate the impact on indoor air quality, of operating unvented heaters, tests were conducted in a two-story test house located in Ottawa during the winter of 1983/84. The emission rates of unused convective and a radiant type heaters and the associated levels of combustion products that resulted from operating them in the living room, bedroom, or basement were measured. With the heater in the living room, the house air infiltration rate was varied; with it in the bedroom, the door and window positions were varied; and with it in the basement, the basement door was either open or closed. These tests supplemented earlier ones conducted by Clarkson et al. (1984) in the same test house, when measurements of heater stability and surface temperature as well as levels of emission products were determined.

The emission rates of the two kerosene space heaters were compared with those of other studies, as were the levels of combustion products under various test configurations inside the test house compared with acceptable limits for each contaminant. The values of the mixing factor to be used with the ventilation model for estimating air contaminant levels were determined from the results.

## TEST METHOD

All tests were conducted in a two-story wood-frame house with a floor area of 118 m<sup>2</sup> (1270 ft<sup>2</sup>) and a volume, including basement, of 386 m<sup>3</sup> (13 600 ft<sup>3</sup>). It is well insulated, having a heat loss factor of 113 W/K and an air vapor barrier of 4-mil polyethelene sheathing over the ceilings and outside walls. The house has a central forced-air electrical heating system.

Figure 1 shows floor plans, heater locations, and gas-sampling points. The lines from the two gas-sampling points located in each room 1.5 m (5 ft) above the floor were manifolded to yield an average gas sample for that room. The radiant type (glass wool wick) space heater

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had a rated capacity of 2.64 kW (9000 Btu/h); and the convective type (cotton wick) had a rated capacity of 2.55 kW (8700 Btu/h). Both heaters were operated according to the instruction manuals supplied by the manufacturers.

An insulated attached garage served as instrument room, permitting measurements to be conducted remotely so that the test house was unoccupied during the tests. Gas samples from the living room, bedroom, basement, and outdoors were drawn by diaphragm pumps through plastic tubing of 3.2 mm (1/8 in) inside diameter to the sampling switch in the instrument room and from there to the gas analyzers: NO/NO<sub>2</sub> (chemiluminescent), CO (nondispersive infrared), CO<sub>2</sub> (nondispersive infrared), and O<sub>2</sub> (paramagnetic). The output from the analyzers was recorded automatically on magnetic tape at 12-minute intervals for each sampling point. Each gas analyzer was checked with a calibration gas before and after each test. Fuel consumption rate during the test was determined by measuring the weight loss of the kerosene space heater (including the fuel reservoir) on a balance with a continuous readout. Air temperatures at all gas sampling points were measured with copper-constantan thermocouples.

The house air infiltration rate was measured before and after each test by means of the tracer gas decay technique (ASTM E741), using sulfur hexafluoride as the tracer gas and an electron-capture detector chromatograph to measure tracer gas concentration. The tracer gas was injected into the house through tubing from the instrument room to the return air duct of the central heating system with the furnace fan running to ensure mixing of tracer gas and air. During the decay period gas samples were drawn from the return air duct through tubing to the detector, and concentrations were measured at five-minute intervals for a period of one hour.

The first series of tests was conducted to determine the emission rates of combustion products from operation of both radiant and convective heaters burning either 1-k kerosene or jet fuel. In the second series each heater was tested in turn, burning only 1-k kerosene in the living room, bedroom, or basement and measuring the concentrations of combustion products in each room.

#### Emission Rate Measurement

Emission rates of CO, CO<sub>2</sub>, NO, and NO<sub>2</sub> from the two test heaters were determined using the mass balance method (comparison of the mass balance and the direct flue gas collection method has been described by Moschandreas et al. [1984]). For this purpose the living/dining room was converted into a test chamber of 60.9 m<sup>3</sup> (2150 ft<sup>3</sup>) by using plastic sheets to cover the floor and windows and plywood sheets to cover large openings to the hallway and kitchen. Windows and doors of the rest of the house were left open for massive ventilation in order to minimize reentry of combustion products to the test chamber. A small fan was used to induce the desired air-change rate inside the test chamber, and a floor fan inside the chamber was operated to promote mixing of combustion products and air. The heater, which was placed on the weight balance in the center of the test chamber, was operated for one hour and shut down from outside the chamber. Concentrations of CO, CO<sub>2</sub>, NO, and NO<sub>2</sub> inside and outside the test chamber were recorded for the one-hour test period and for 15 minutes after the heater was shut down.

Six tests were conducted for each space heater, with air-change rates of about 1/4, 1/2, and 1 per hour, burning either 1-k kerosene or jet fuel. The two fuels (which were analyzed by the Petroleum and Gas Laboratories, CANMET, Energy, Mines and Resources Canada) had carbon and hydrogen contents of 86.5% and 13.6% by weight and negligible sulfur content. The nitrogen content was 2 ppm by weight for the kerosene fuel and 6 ppm for the jet fuel. The heat of combustion was 46 000 kJ/kg (19 800 Btu/lb) for both fuels.

The concentration of indoor air contaminants can be described by the equation of Alonzo et al. (1979), with the mixing factor added according to Ishizu (1980):

$$dC = PmC_o dt + \frac{S}{V} dt - (ma + k)Cdt, \quad (1)$$

where

- C = indoor contaminant concentration (ppm or µg/m<sup>3</sup>)
- C<sub>o</sub> = outdoor contaminant concentration (ppm or µg/m<sup>3</sup>)
- P<sub>o</sub> = fraction of outdoor contaminant level entering the house through the building envelope (unitless)
- m = mixing factor (unitless)

- $a$  = air exchange rate in air changes per hour ( $\text{h}^{-1}$ )  
 $S$  = source emission rate ( $\text{mL/h}$  or  $\mu\text{g/h}$ )  
 $V$  = volume ( $\text{m}^3$ )  
 $k$  = reactivity, net rate of removal processes other than air exchange ( $\text{h}^{-1}$ )

Assuming  $C_0$ ,  $P$ ,  $a$ ,  $S$  and  $k$  to be constant over the time period of interest, Equation 1 can be solved for  $C(t)$  to give:

$$C(t) = \frac{PmaC_0 + S/V}{ma + k} [1 - e^{-(ma + k)t}] + C(0)e^{-(ma + k)t} \quad (2)$$

At steady state

$$C(s) = \frac{PmaC_0 + S/V}{ma + k} \quad (3)$$

where  $C(s)$  = concentration at steady state.

If the source is removed at  $t = 0$ , i.e.,  $S = 0$ , and if  $C_0 = 0$ , the air contaminant decays exponentially from the peak concentration,  $C_p$ , according to

$$C(t) = C_p e^{-(ma + k)t} \quad (4)$$

Rearranging and taking the natural logarithm on both sides

$$(ma + k) = \frac{-\ln(C(t)/C_p)}{t} \quad (5)$$

The air change rate ( $a$ ) was determined from the  $\text{SF}_6$  tracer gas decay readings (assuming  $m = 1$ ). Values for reactivity ( $k$ ) were calculated from readings of the concentration of combustion product during the decay period after the space heater was turned off and using Equation 5. The source emission factors in  $\mu\text{g/kJ}$  were calculated by solving for  $S$  using Equation 2 and dividing it by the fuel consumption rate in  $\text{kJ/h}$ . The above calculations were made assuming values of  $m = P = 1$ .

#### House Test

From a base house temperature of  $15^\circ\text{C}$  ( $60^\circ\text{F}$ ) for all tests, the heater was operated with kerosene fuel until either the level of carbon dioxide reached steady state or the air temperature in the room with the heater reached  $28^\circ\text{C}$  ( $82^\circ\text{F}$ ). The heater was placed in the living room, bedroom, or basement at locations indicated in Figure 1. In all, twelve tests were conducted with the radiant heater and seven with the convective heater (Table 1).

With a heater in the living room, the house air change rate was varied from about 0.25 to 1 ach by opening the casement windows of the first and second floors as required. With the heater in the bedroom ( $39 \text{ m}^3$ ,  $1380 \text{ ft}^3$ ), tests were conducted as follows: window and door of the bedroom closed; window closed and door open 50 mm (2 in) or wide open; window open 25 mm (1 in) and door closed. With the heater in the basement ( $100 \text{ m}^3$ ,  $3530 \text{ ft}^3$ ), tests were conducted with the basement door to the first floor either open or closed. House tests with the heater in the living room, bedroom, or basement were conducted with the furnace fan of the central heating system off, except for tests with the fan operating as indicated in Table 1. As there was a highway south of the house, tests were not made when there was no wind or wind from the south since the outdoor concentration of combustion products varied substantially with traffic volume.

#### RESULTS AND DISCUSSION

The results of the six emission rate tests for  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{NO}$ , and  $\text{NO}_2$  are summarized in Table 2, which includes values from other tests (Porter 1984). Emission rates from burning 1-k kerosene and jet fuel were combined since they gave similar results. Emission rates of  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{NO}$ , and  $\text{NO}_2$  for the radiant heater averaged 170, 78 000, 0.71, and  $4.8 \mu\text{g/kJ}$ , respectively; for the convective heater they were 30, 77 000, 23.0, and  $7.8 \mu\text{g/kJ}$ , respectively.  $\text{CO}$  production for the radiant heater was about five times that for the convective heater, whereas  $\text{NO}_2$  production was about two-thirds of it; similar results have been obtained by other investigators (Table 2). Porter (1984) reported that when the wick was

lowered for heaters with an enclosed flame (blue flame) and an open flame (white flame), the CO emission rate increased by 40% and 200%, respectively; similarly, Traynor (1985) reported increases in CO emission rates of 62% and 830%, and Leaderer (1982) reported values of 25% and 15%. Such values make it clear that maladjustment of heaters can result in a significant increase in CO production.

Reactivity is a measure of the rate of disappearance of a contaminant by mechanisms other than dilution (i.e., absorption, adsorption, oxidation, etc). The mean reactivity rate for NO was  $0.083 \pm 0.054 \text{ h}^{-1}$  and that for  $\text{NO}_2$  was  $0.82 \pm 0.34 \text{ h}^{-1}$ ; values of  $0.030 \pm 0.03 \text{ h}^{-1}$  and  $0.74 \pm 0.21 \text{ h}^{-1}$  were obtained when the kitchen was used as a test chamber during gas cooking stove tests in a similar test house (Goto and Tamura 1984).

In the present series, tests were conducted first with the heater in the living room, then with it in the master bedroom and basement. As all were run either to steady state, based on  $\text{CO}_2$  concentration, or a terminal temperature of  $28^\circ\text{C}$  ( $82^\circ\text{F}$ ), burn time varied from test to test. The rates of fuel consumption, however, were relatively constant, with values of 170 and 160 g/h ( $0.37$  and  $0.35 \text{ lb/h}$ ) for the radiant and convective heaters, respectively (Figure 2). These values correspond to maximum heat output of 2.1 kW (7300 Btu/h) and 2.0 kW (6900 Btu/h), about 80% of the rated capacities. The values for oxygen depletion for all tests (including those in the bedroom with door and window closed) were less than 0.1%, which is much less than the critical value of 2% above which the emission rate of CO increases significantly (Yoshizawa 1984).

#### Heater in Living Room

The tests were conducted at house air change rates of about  $1/4$ ,  $1/2$ , and 1 ach. The concentration of  $\text{NO}_2$  is plotted in Figure 3 against the sum of air infiltration rate and reactivity; CO and  $\text{CO}_2$  are plotted against air infiltration rate only, since these values of reactivity were found to be negligible. As Equation 3 suggests, the steady-state concentrations of combustion product varied inversely as the sum of air infiltration and reactivity; the concentrations of combustion products from both the radiant and convective heaters were in proportion to their emission rates.

Concentrations in the bedroom were somewhat higher than those in the living room; concentrations in the basement were much lower than those in the floors above. Test No. R4, furnace circulation fan operating, resulted in considerable equalization of the contaminant concentrations for all three levels (Figure 3). The maximum temperature rise in the living room was about  $5^\circ\text{K}$  ( $9^\circ\text{F}$ ); as a result, all tests were run to steady state, based on  $\text{CO}_2$  concentrations.

With the radiant heater, test No. R7, the maximum measured level of CO equaled the ASHRAE Standard 62-1981 limit of 9 ppm for an eight-hour exposure, but it was far less than the limit of 36 ppm for a one-hour exposure. The  $\text{CO}_2$  level of 2730 ppm just exceeded the ASHRAE limit of 2500 ppm for continuous exposure. With the convective heater, test No. C1, only the  $\text{CO}_2$  value of 2630 ppm in the bedroom exceeded the limit.  $\text{NO}_2$  levels in all tests with the convective heater in the living room were close to or just above the limit of 0.055 ppm for a yearly exposure (ASHRAE 1981). With the radiant heater they were below this limit for all tests. The results indicate, therefore, that operating the test heaters in the living room with open connections to other areas of the house did not result in maximum contaminant concentrations much in excess of the limits for various exposures given in the ASHRAE ventilation standard.

#### Heater in the Bedroom

The house air infiltration rates for these tests were about  $1/4$  ach. The contaminant levels for all except test No. R5 were far higher in the bedroom than in either the living room or basement. With the furnace fan operating (test No. R5) and supply and return grilles in the floor of the bedroom, concentrations in the basement were about the same as those in the bedroom; those in the living room were about one-half. For test No. R6, with the bedroom door wide open, concentrations in the living room were about half of those in the bedroom; concentrations in the basement were as low as those in test No. 7 with the bedroom door closed.

Figures 4, 5, and 6 give concentrations of CO,  $\text{CO}_2$ , and  $\text{NO}_2$  with burn time for various tests conducted in the bedroom. As expected, the highest concentrations were obtained when both window and door were closed. Substantial reductions in concentration were obtained when

the door was opened 50 mm (2 in), or 0.11 m<sup>2</sup> (1.2 ft<sup>2</sup>), and when the door was open wide. Opening the window by 25 mm (1 in), or 0.039 m<sup>2</sup> (0.42 ft<sup>2</sup>), resulted in a greater reduction than opening the door by 50 mm (2 in), probably owing to enhanced exfiltration as a result of stack action.

CO levels, as shown in Figure 4, were much higher for the radiant heater than for the convective heater, as would be expected from their respective emission rates. With the window and door of the bedroom closed, the limit of 9 ppm was exceeded at 0.4 and at 3.0 hours for the radiant and convective heaters, respectively. For other conditions the eight-hour exposure limit for CO was exceeded only with the radiant heater: at 0.6 hour with the bedroom door open 50 mm (2 in); at 3.2 hours with bedroom door and window closed and furnace fan operating; and at 4.6 hours with the bedroom door wide open. The one-hour exposure limit of 36 ppm was exceeded with the radiant heater for test No. R7 with both window and door closed. The limit of 2500 ppm for CO<sub>2</sub> was exceeded, as may be seen in Figure 5, for all test conditions for both heaters. With the window and door closed, it was exceeded at 0.5 hour for both heaters. As may be seen in Figure 6, the limit of 0.055 ppm for NO<sub>2</sub> was exceeded in all tests with either heater. Opening a window or a door resulted in reduced levels of all combustion products, as was also noted by Clarkson et al. (1984) and Ritchie and Arnold (1984). Cooper and Alberti (1984) found that homeowners of 13 of the 14 homes investigated left the doors open to adjacent rooms during operation of kerosene space heaters, but were reluctant to open a window as recommended by the heater instructions because of cooling from inflow of cold air.

Figure 7 shows the air temperatures in the bedroom for the various tests. As expected, room temperatures were highest when both window and door were closed, followed by cases with window open 25 mm or the door open 50 mm. The room temperatures were substantially lower when the door was left wide open. Although the burn time was much longer for this case than for that with window and door closed, the contaminant levels were much less.

#### Heater in the Basement

With the radiant heater in the basement and the basement door closed (test No. R10), the maximum CO, CO<sub>2</sub>, and NO<sub>2</sub> levels were 16, 5500, and 0.097 ppm. These were reduced by about one half when the basement door was opened (test No. R11) and were even lower with it closed and the furnace fan operating (test No. R12). In test No. R10 the levels of CO and CO<sub>2</sub> in the living room and bedroom were about 1/4 and 1/3 of those in the basement, whereas in test No. R11 and R12 the levels approached those of the basement. For the convective heater, only one test was conducted: with basement door closed and furnace fan off (test No. C7). Except for a CO value of 3.4 ppm, maximum levels of 4880 ppm for CO<sub>2</sub> and 0.25 ppm for NO<sub>2</sub> exceeded their respective limits. The temperature rise for all basement tests varied from 2.9 to 4.3°C (3.6 to 7.7 F).

#### Calculation of Contaminant Levels (mixing factor)

Levels of combustion products from heaters of a given size and type located in a given space can be calculated by means of Equation 2, using known emission rates and the mixing factor. Based on CO and CO<sub>2</sub> measurements, mixing factors were calculated using Equation 3 and assuming that P = 1 and k = 0 as follows:

$$m = \frac{S/v_h}{a_t(C(s) - C_o)} \quad (6)$$

#### where

$V_h$  = total house volume, m<sup>3</sup>  
 $a_t$  = measured house air change rate, h<sup>-1</sup>

Equation 6 makes use of house air infiltration rate,  $a_t$ , and total house volume,  $V_h$ , to determine the mixing factor,  $m$ , based on CO and CO<sub>2</sub> measurements; all air entering a house with interconnected spaces is potentially available for diluting combustion products. With complete mixing of outside air and combustion products, the value of  $m$  is equal to one; with incomplete mixing,  $m$  can be less or greater than one. The mixing factor is a function of the distribution of infiltration air through the house envelope and the combustion products within the house and the air circulation in the house spaces. The magnitude of  $m$  depends upon the location of the gas-sampling points and the heater with respect to flow of dilution air. A



value of  $m$  less than unity implies that a below-average amount of infiltration air is available for dilution or that the combustion products are above average near the sample point;  $m$  greater than unity indicates the reverse. The resulting contaminant levels would be higher in the former case than in the latter for the same source strength.

The average value of  $m$  for the living room tests (12 tests), taking  $C(s)$  equal to the average of the living room and bedroom concentrations, was calculated to be 1.3, with a standard deviation of 0.36. The value of  $m > 1$  was probably due to the buoyant plume from the heater, resulting in nonuniform mixing in the living room and a lower concentration of combustion products at the gas-sampling points than at the upper levels. Assuming a value of  $m = 1$  gives a conservative estimate of the contaminant levels (Eq. 2). For the basement test with door closed and furnace fan off, the average value of  $m$  was calculated to be 0.8 (range of 0.69 to 0.95); with the basement door open and the furnace fan off,  $m = 1.2$  (range of 0.96 to 1.4); and with the basement door closed and the furnace fan on,  $m = 1.1$  (one reading).

For the bedroom tests with both window and door closed, the average value of  $m$  was calculated to be 0.4 (range of 0.32 to 0.45); with the window closed and the door open 50 mm (2 in),  $m = 0.9$  (range of 0.7 to 1.0); with the window closed and the door wide open,  $m = 1.2$  (range of 1.1 to 1.2); with the window open 25 mm (1 in) and the door closed,  $m = 1.3$  (range of 0.9 to 1.8).

Tests with unvented gas-fired space heaters in either the living room or the bedroom of a one-story house (240 m<sup>3</sup>, 8480 ft<sup>3</sup>) were conducted by Traynor et al. (1985). The results indicated that with all interior doors open the pollutants mixed rapidly throughout the house, with concentrations of CO<sub>2</sub> in the various rooms within 14% of the mean for all tests. The mixing factor for this case was probably close to one.

#### SUMMARY

Tests with radiant and convective space heaters whose measured heat outputs were 2.1 kW (7300 Btu/h) and 2.0 kW (6900 Btu/h), respectively, indicated the following:

1. The source emission factors of CO, CO<sub>2</sub>, NO, and NO<sub>2</sub> determined by the mass balance technique for both heaters are shown in Table 2.
2. Tests with the radiant heater in the living room and a rate of 1/4 air change per hour gave maximum levels of CO and CO<sub>2</sub> that just exceeded the limits of 9 ppm (8-h) and 2500 ppm (continuous), respectively; tests with the convective heater gave similar CO<sub>2</sub> levels. The maximum levels of NO<sub>2</sub> in all tests with the convective heater were close to or just above the limit of 0.055 ppm (yearly); with the radiant heater, on the other hand, they were below this limit. The maximum temperature rise in the living room was 5 K (9 F).
3. With the heaters in the bedroom, the limit for CO (eight hours) was exceeded with the radiant heater (all tests) except when the window was open 25 mm; it was exceeded with the convective heater only when both the window and door were closed. The limit of 36 ppm for CO (one hour) was exceeded only with the radiant heater when both the window and door were closed. The limit for CO<sub>2</sub> was exceeded in all tests with both heaters. The limit for NO<sub>2</sub> was exceeded by both heaters in all tests.
4. In the basement tests, with the basement door closed and the furnace fan off the limits for CO (eight hours), CO<sub>2</sub>, and NO<sub>2</sub> were exceeded with the radiant heater, and those for CO<sub>2</sub> and NO<sub>2</sub> were exceeded with the convective heater. With the radiant heater, only the CO<sub>2</sub> concentrations exceeded the limit when the basement door was opened. The temperature rise for all basement tests varied from 2.9 to 4.3°C (3.6 to 7.7 F).
5. The average values of the mixing factor at gas-sampling points 1.5 m (5 ft) above floor level were  $m = 1.3$  for the living room tests,  $m = 0.8$  for the basement tests, and  $m = 0.4$  for the bedroom tests. The mixing factor was increased for the bedroom test to 0.9 with the door open 50 mm (2 in) and to 1.3 with the door closed and the window open 25 mm (1 in).

#### CONCLUSIONS

Test results indicate that the operation of kerosene space heaters in a house can result in levels of combustion products that exceed the limits set by ASHRAE Standard 62-1981, particularly within a small volume such as a bedroom, house trailer, or cabin. The use of improperly tuned or maintained heaters in such spaces could result in CO levels well above acceptable limits. Increasing the ventilation rate of the room containing the heater can

reduce the contaminant levels, but owing to lower air temperature rise it can result in longer burn time and, hence, longer exposure time. The general ventilation equation (Equation 2) can be used as a guide in estimating air contaminant levels for heaters of various emission rates, house volumes, and air infiltration rates, but more data on mixing factors are required.

#### REFERENCES

- Alonzo, J.; Cohen, B.L.; Rudolph, H.; Jow, H.J.; and Frohlinger, J.O. 1979. Indoor-outdoor relationships for airborne matter of outdoor origin. *Atmospheric Environment*, Vol. 13, No. 55.
- ASHRAE 62-1981, Ventilation for acceptable indoor air quality.
- ASTM E741. Standard practice for measuring air leakage rate by tracer dilution method.
- Clarkson, S.G.; Tom, B.L.; Babcock, A.J.; and Mehkeri, K.A. 1984. Results of testing unvented kerosene heaters in a house: Gas emissions, surface temperatures and fuel consumption rates. Presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, CA, 24-29 June.
- Cooper, K.R.; and Alberti, R.R. 1984. Effect of kerosene heater emissions and indoor air quality and pulmonary function. *American Review of Respiratory Disease*, Vol. 129, pp. 629-631.
- Goto, Y.; and Tamura, G.T. 1984. Measurement of combustion products from a gas cooking stove in a two-storey house. Presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, CA, 24-29 June.
- Leaderer, B.P. 1982. Air pollutant emissions from kerosene space heaters. *Science*, Vol. 218, pp. 113-115.
- Ishizu, Y. 1980. General equation for the estimation of indoor pollution. *Environmental Science and Technology*, Vol. 14, No. 10 (October), pp. 154-1257.
- Moschandreas, D.J.; Relwani, S.M.; Macriess, R.A.; and Cole, J.T. 1984. Differences and similarities of two techniques used to measure emission rates from unvented gas appliances. *Proceedings of the 3rd International Conference on Indoor Air Quality and Climate*, Stockholm, Sweden, 20-24 August, Vol. 4, pp. 375-379.
- Porter, W.K., Jr. 1984. Pollutant emissions from kerosene heaters and unvented gas space heaters. *Proceedings of the 3rd International Conference on Indoor Air Quality and Climate*, Stockholm, Sweden, 20-24 August, Vol. 4, pp. 265-269.
- Ritchie, I.M.; and Arnold, F.C. 1984. Characterization of residential air pollution from unvented kerosene heaters. *Proceedings of the 3rd International Conference on Indoor Air Quality and Climate*, Stockholm, Sweden, 20-24 August, Vol. 4, pp. 253-256.
- Traynor, G.W.; Girman, J.R.; Apte, M.G.; Dillworth, J.F.; and White, P.D. 1985. Indoor air pollution due to emissions from unvented gas-fired space heaters. *Journal of the Air Pollution Control Association*, Vol. 35, No. 3 (March), pp. 231-237.
- Yoshizawa, S. 1984. Japanese experiences on the control of indoor air pollution by combustion appliances. *Proceedings of the 3rd International Conference on Indoor Air Quality and Climate*, Stockholm, Sweden, 20-24 August, Vol. 5, pp. 193-198.

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TABLE 1  
Description of House Tests

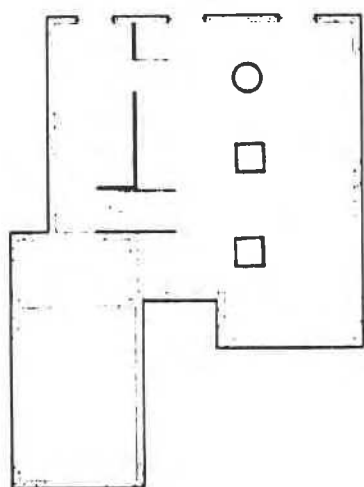
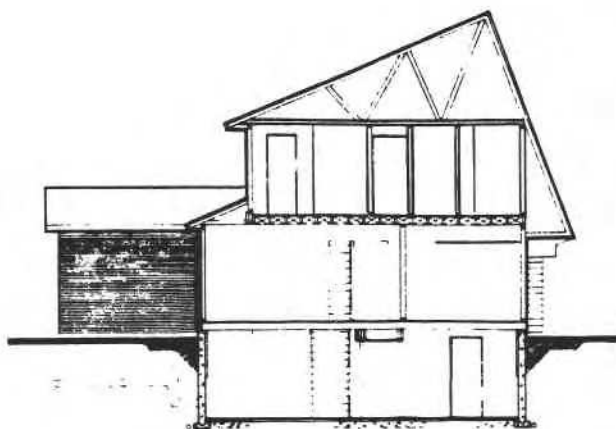
Test No.	Heater Location	House ach	Basement Door	Bedroom Door	Bedroom Window	Furnace Fan
Radiant Heater						
R1	LR	0.25	C	O	C	off
R2	LR	0.60	C	O	C	off
R3	LR	0.96	C	O	C	off
R4	LR	0.44	C	O	C	on
R5	MBR	0.25	C	C	C	on
R6	MBR	0.22	C	O (wide)	C	off
R7	MBR	0.25	C	C	C	off
R8	MBR	0.22	C	O (50 mm)	C	off
R9	MBR	0.38	C	C	O (25 mm)	off
R10	BSMT	0.22	C	O	C	off
R11	BSMT	0.26	O	O	C	off
R12	BSMT	0.53	C	O	C	on
Convective Heater						
C1	LR	0.20	C	O	C	off
C2	LR	0.44	C	O	C	off
C3	LR	0.95	C	O	C	off
C4	MBR	0.22	C	C	C	off
C5	MBR	0.25	C	O (50 mm)	C	off
C6	MBR	0.31	C	C	O (25 mm)	off
C7	BSMT	0.27	C	O	C	off

Note: 1. 1-k kerosene fuel used for all tests 4. BSMT = basement  
 2. LR = living room 5. C = closed, O = open  
 3. MBR = master bedroom

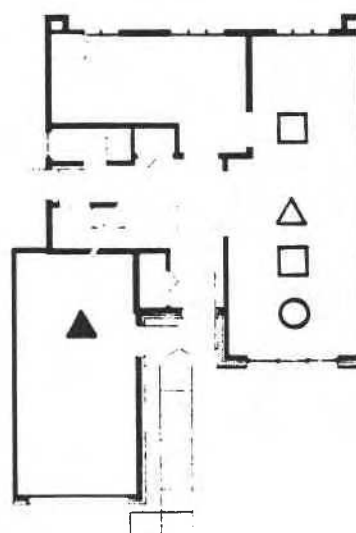
TABLE 2  
Experimental Values of Source Emission Factor ( $\mu\text{g}/\text{kJ}$ )

Space Heater	CO	CO <sub>2</sub>	NO	NO <sub>2</sub>
Radiant				
NRCC	170	78 000	0.71	4.8
Traynor	66.0	70 300	1.4	4.5
Leaderer	58.2		0.1	5.0
Jones	55.2 - 97.6		0.8 - 1.6	3.3 - 4.0
Porter	125.9		0.1	4.7
Convective				
NRCC	30	77 000	23.0	7.8
Traynor	12.4	71 300	24.2	13.7
Leaderer	22.3		11.7	14.5
Jones	9.3		14.6	7.1
Porter	23.9		14.4	7.2

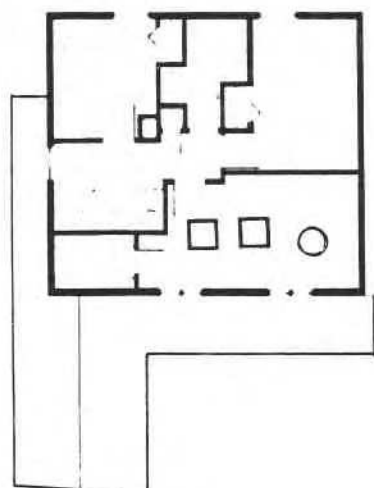
Note: Values other than those of NRCC were taken from Porter (1984).



BASEMENT PLAN



GROUND FLOOR PLAN



SECOND FLOOR PLAN

- △ HEATER LOCATION - EMISSION RATE TEST
- HEATER LOCATION - HOUSE TEST
- GAS SAMPLING LOCATIONS
- ▲ INSTRUMENT ROOM

Figure 1. Test house

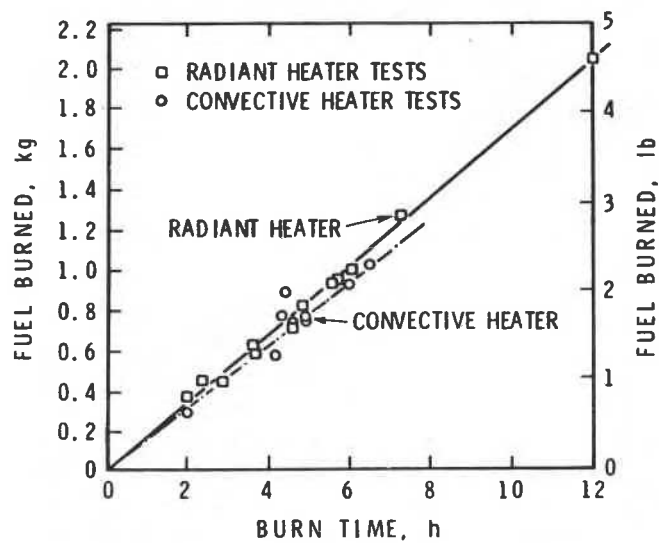


Figure 2. Fuel consumption vs. burn time

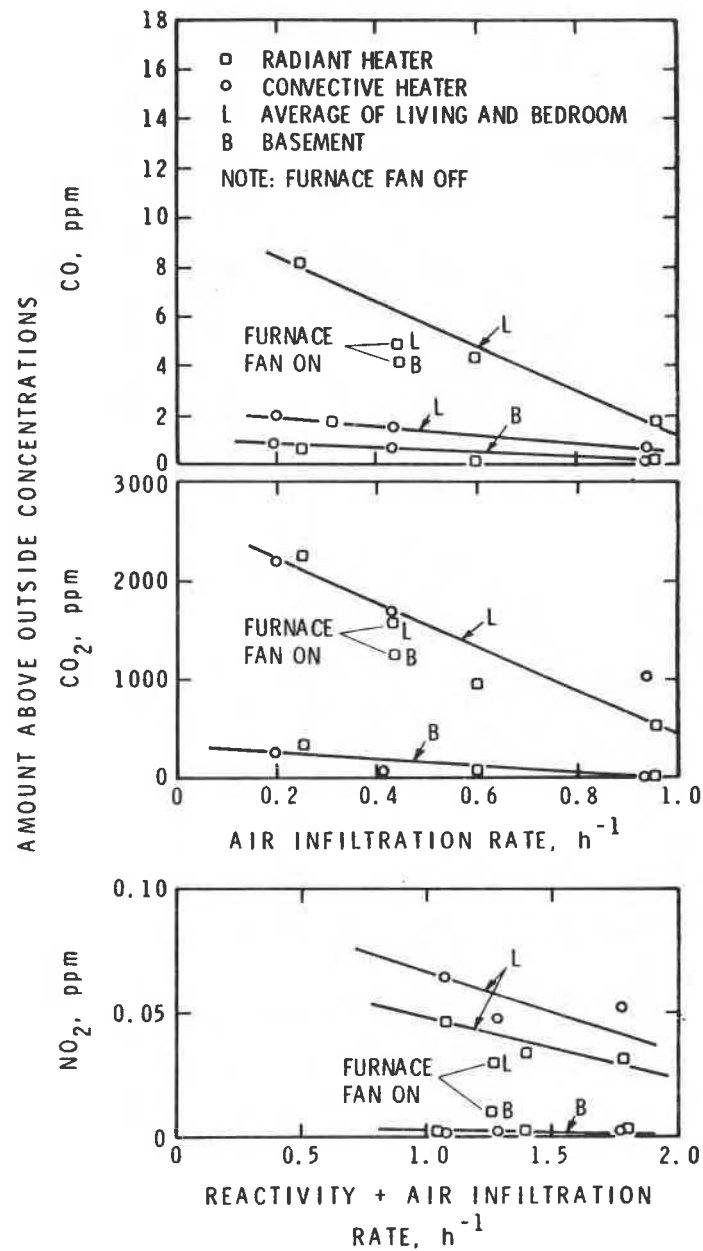


Figure 3. Concentrations of combustion products vs. air infiltration rate, heater in living room

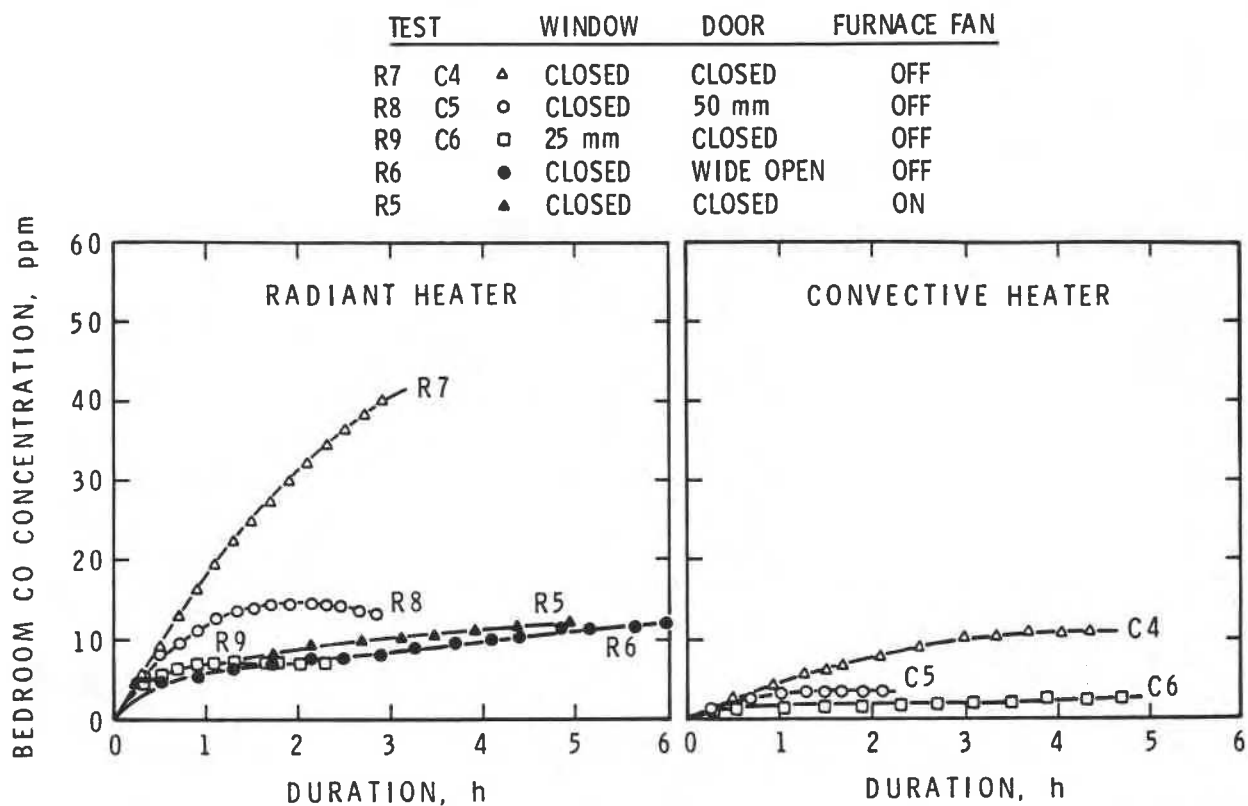


Figure 4. Carbon monoxide concentrations during bedroom tests

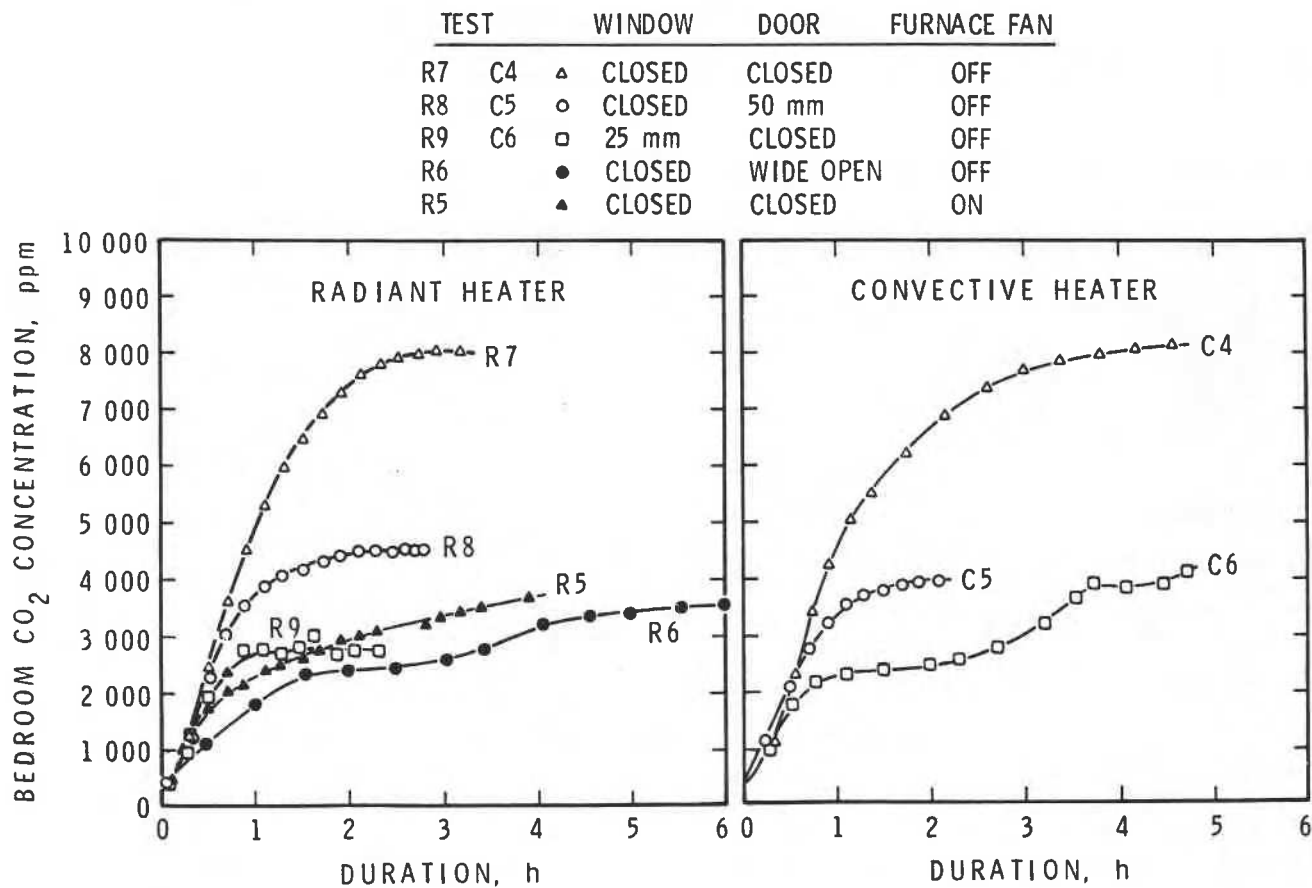


Figure 5. Carbon dioxide concentrations during bedroom tests

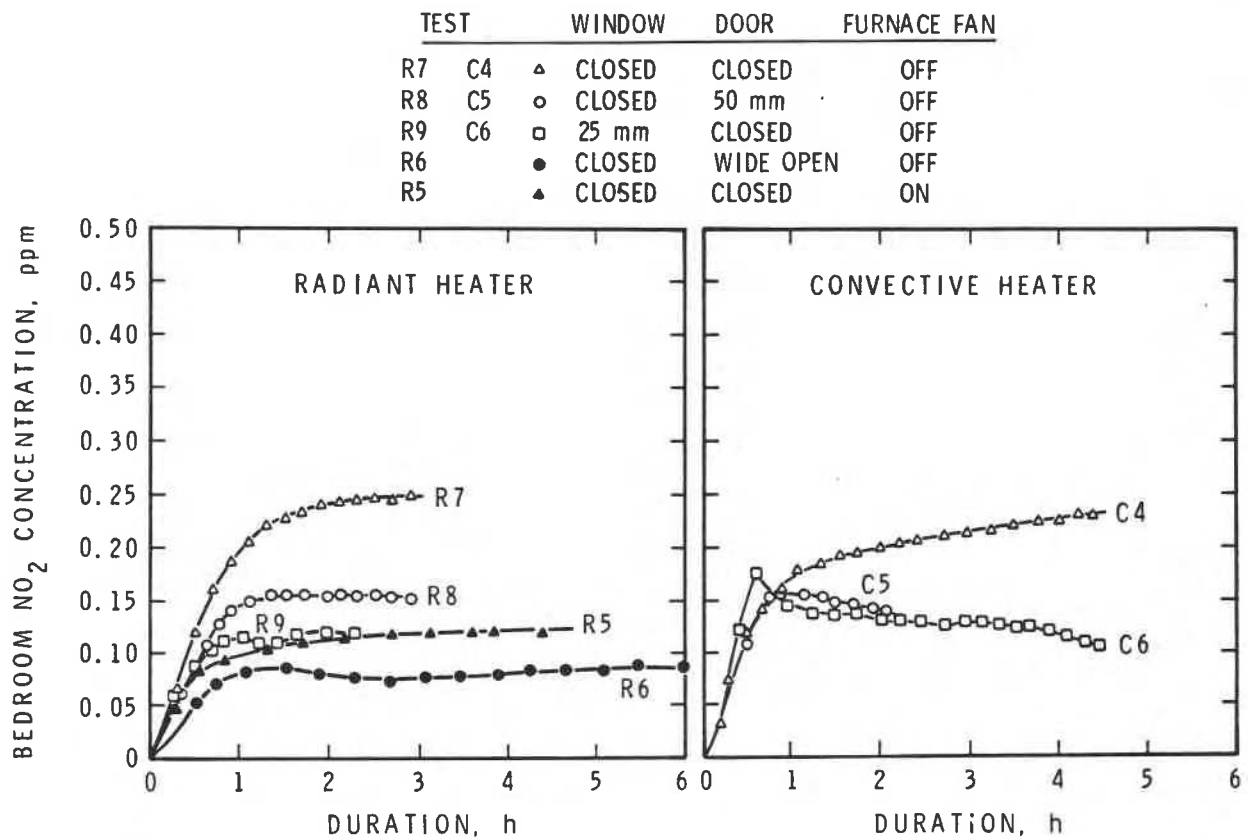


Figure 6. Nitrogen dioxide concentrations during bedroom tests

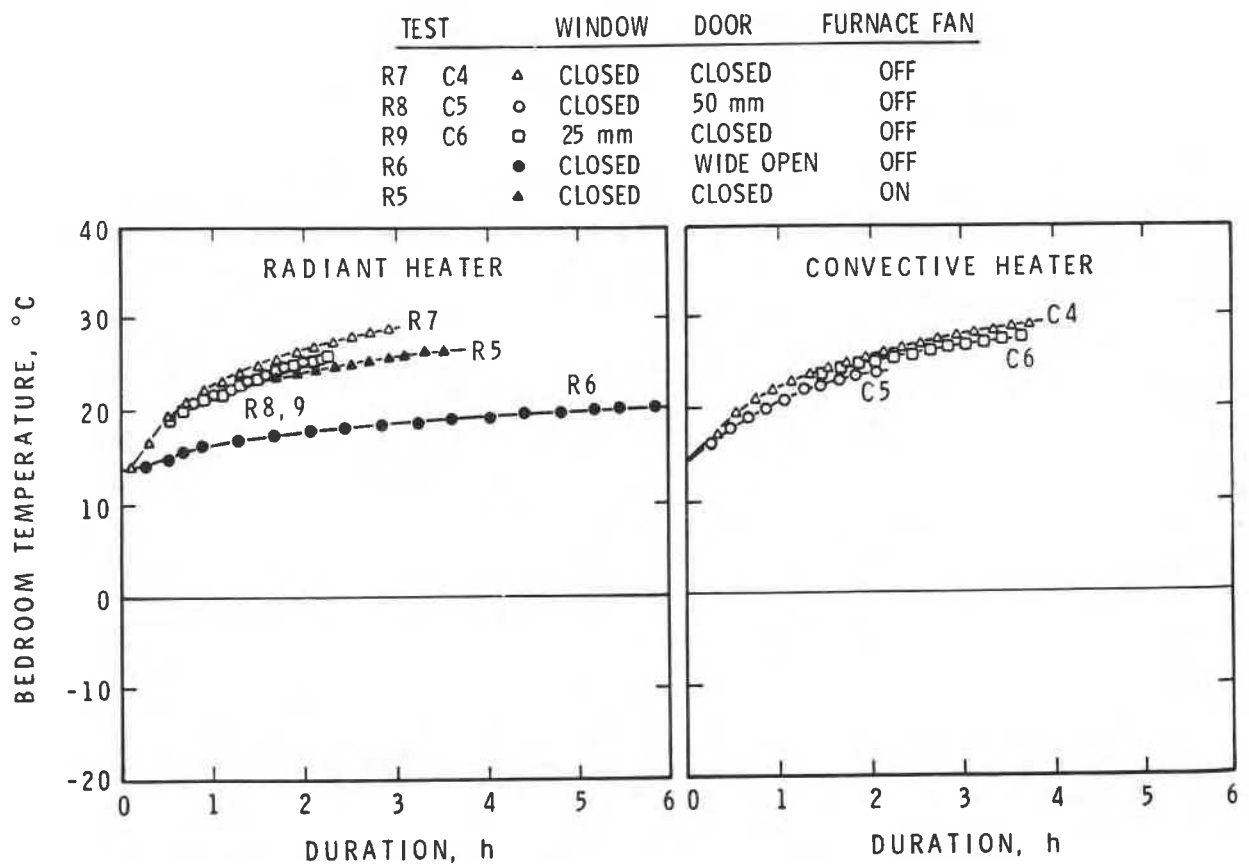


Figure 7. Air temperatures during bedroom tests

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