#6426

O·R·I·G·I·N·A·L P·A·P·E·R

Indoor Environ 1992;1:272–278

Ron Williams[a]
Debra Walsh[a]
James White[b]
Merrill Jackson[b]
Judy Mumford[b]

[a] Environmental Health Research and Testing; and
[b] US Environmental Protection Agency, Research Triangle Park, N.C., USA

Effect on Carbon Monoxide Levels in Mobile Homes Using Unvented Kerosene Heaters for Residential Heating

Key Words
Carbon monoxide
Unvented kerosene heaters
Mobile homes

Abstract
Carbon monoxide (CO) emission levels were continuously monitored in 8 mobile trailer homes less than 10 years old. These homes were monitored in a US Environmental Protection Agency study assessing the effects of unvented kerosene heaters on indoor air quality. Respondents were asked to operate their heaters in a normal fashion. CO, air exchange rates and temperatures were measured during the study in each home. Results indicated that these small homes (<100 m^2 internal space), having low air exchange rates/h (<0.5), showed elevated indoor CO levels during heater use. Three of the 8 homes in the study had 8-hour averages above or near the 9-ppm US standard for exposure. Seven of the homes were found to have a significant increase of CO during combustion periods as compared with background levels; one home routinely had levels of 30–50 ppm for prolonged exposures. These results may indicate that consumers using unvented kerosene heaters are being unknowingly exposed to high CO levels and thus not taking proper precautions.

Introduction

A report prepared for the US Environmental Protection Agency (EPA) estimates that 15–17 million portable kerosene heaters have been purchased since the early 1970s. Present annual sales approach 825,000 units [1], and nearly 7 million are in use nationwide. The southern US represents nearly 50% of the US market. Approximately 33% of all unvented kerosene heaters are estimated to be used in mobile homes (trailers) [1]. Convective heater designs represent almost 60% of the units sold, with radiant models comprising the majority of the remaining 40%. These values are expected to change in the future as new multistage heaters become more commercially available.

Carbon monoxide (CO) is a known combustion product of unvented kerosene heaters with indoor levels depending upon many factors (heater type, fuel, ventilation, combustion period) [2–7]. These levels have reportedly ranged from low background (0–2 ppm) to values near or above the 35-ppm 8-hour occupational standard [3, 4, 6–9]. The purpose of this study was to measure the effect on CO concentrations in unvented mobile homes when portable kerosene space heaters were used as a supplemental or primary heating source. It was postulated that the use of these heaters in small-volume homes would result in

Accepted:
January 10, 1992

Ron Williams
Environmental Health Research and Testing
P.O. Box 12199
Research Triangle Park, NC 27709 (USA)

1016–4901/92/0015–0272
$2.75/0

Table 1. Home and heater information

Home			Heater			Rated		Average[a]
No.	age years	indoor area, m^2	age years	brand	type	BTU/h	kJ/h	BTU/h %
1	2	97.1	0	Omni 105	convective	20,000	21,095	80.3
2	2	79.9	3	Toyokuni 200 EU	convective/dual comb	20,000	21,095	86.3
3	1.5	66.4	1	Omni 105	convective	20,000	21,095	75.5
4	3	78.1	2	Everglow PE-E8	convective	20,000	21,095	88.7
5	9	88.2	3	Sanyo OHRG25A	radiant/dual flame	9,500	10,020	66.7
6	1.5	79.4	4	Moon lighter	convective/radiant	8,700	9,177	83.0
7	2	91.5	5	Koehring	radiant	6,800	7,172	169.0
8	2	79.6	5	Alladin[b] Happy 2 P320001	radiant	unknown	unknown	unknown

[a] Average BTU/h is based upon average fuel consumption from all trials for each heater.
[b] The Alladin is no longer manufactured and no information could be obtained concerning its BTU/h rating.

Table 2. Mobile-home study sampling design: schedule for heater use and nonuse in each home

Home	Week 1	Week 2	Week 3	Week 4
1	on	off	on	off
2	on	off	on	off
3	off	on	off	on
4	off	on	off	on
5	off	on	on	off
6	on	off	off	on
7	on	off	off	on
8	off	on	on	off

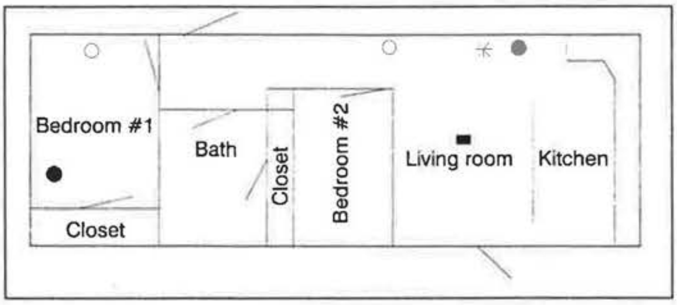

Fig. 1. Typical layout of a mobile home selected for sampling. The outside area measured 4.2 × 15.9 m. ■ = Kerosene heater; ○ = PFT source; ● = PFT receptor; * = CO monitor.

potentially high levels of CO. This would especially be true in mobile homes built after 1974, when energy-saving manufactured-housing standards were put into place, resulting in lower air infiltration rates [1]. Pollutant dilution in these homes would be expected to be lower than those found in an average US single-family dwelling. This study describes the findings of continuous CO monitoring in 8 mobile homes where unvented kerosene heaters were utilized for residential heating.

Materials and Methods

Nonsmoking families residing in single-width mobile homes of less than 97.1 m^2 internal area were selected to participate in the study. 'All-electric' homes were chosen, thus eliminating interference from possible CO production by other fossil fuel combustion sources used for heating or cooking. Selected homes were not in close proximity to obvious CO sources (other homes with wood-burning fireplaces, excess residential traffic). All homes were of recent manufacture (> 1980) and were inspected for structural soundness. Eight homes were chosen which met all the required sampling criteria. The 8 homes had slightly different floor plans, but most had the layout shown in figure 1. A survey was conducted in each home describing the usual heater location, ventilation sources, cooking devices, normal family activities and location of all the sampling and monitoring equipment. A complete list of kerosene heaters monitored in the study and pertinent data is found in table 1.

Respondents participating in this study during the 1989 winter (February–March) were given little instruction on heater use or operations, and were asked to operate their heaters in a customary manner. The study design did, however, specify certain weeks when the heaters in each home could be used. This design (table 2) allowed for greater statistical control of the collected data and interpretation. The families were instructed to use their heaters as they desired any time during 'on'-designated weeks and not to operate the heaters any time during 'off'-designated periods. At least 48 h separated any nonuse period from a potentially active one.

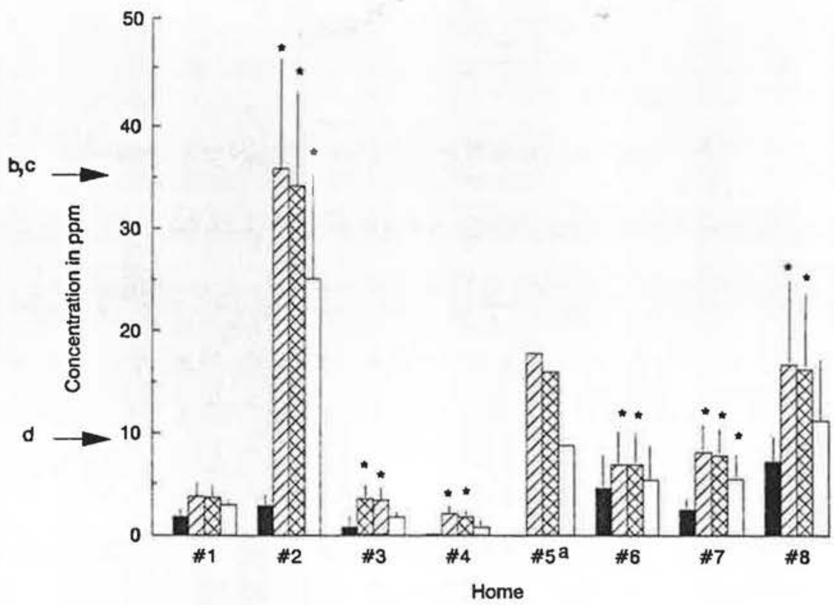

Fig. 2. Average indoor concentrations of CO (ppm). Values are means ± SD; measurements were taken while heaters were in use. * $p = 0.05$, significantly greater than background value. [a]Data from only one measurement, statistical significance could not be performed between background and heater CO values. [b]US Occupational Safety and Health Administration (OSHA) CO standard for 8-hour time-weighted average, 40-hour work week. Code of Federal Regulations, Title 29, Part 1919.1, US Government Printing Office, Washington, D.C., 1988. [c]US ambient-air quality CO standard, 1-hour average not to be exceeded more than 1 time/year. Federal Register, US Government Printing Office, vol 54, No 12 (2651–2652), January 19, 1989. [d]Primary US air quality CO standard, 8-hour average not to be exceeded more than 1 time/year. Code of Federal Regulations, Title 40, Part 50.8, US Government Printing Office, Washington, D.C., 1989. ■ = Background; ▨ = peak; ⊠ = 1-hour average; □ = 8-hour average.

A single lot of K-1 kerosene was provided for use in each home throughout the study in order to eliminate fuel bias. This fuel was analyzed and found to contain polyaromatic hydrocarbons of four or less rings, and was certified as a low-sulfur (K-1) kerosene. Fuel consumption was determined for each burn period by the gravimetric difference of the fuel residing in each heater unit. Portable CO analyzers (General Electric COED-1) equipped with strip chart recorders for continuous monitoring were placed at an average of 2–4 m from the normal location of the heaters. In most cases, this was in the den or living room of a mobile home. Monitors were installed at a height of 0.5 m from the floor in an area where respondents normally sat or reclined. Most families placed their heaters in the center of the den or living room, although one family used a different approach. The family in home 1 placed their heater in front of the internal air supply duct; when the heater was in use, they turned on the furnace fan and circulated the warm air throughout the trailer. The CO monitor was installed in the living room of this home. Each CO monitor was calibrated prior to field placement with zero and span gases and then audited and calibrated at least biweekly during the month of sampling.

Temperature and relative humidity were continuously recorded for each home in the area surrounding the heater. Monitoring units (Belford Hygrothermographs) were placed an average of 3–4 m from the heaters, at a height of 1.5–2 m, depending upon the layout of the home. Continuous outdoor temperature monitors were placed immediately outside of each home.

Indoor air exchange rates were determined using perfluorocarbon tracer technology (PFT). This technique described by Dietz et al. [10] utilizes the slow release of a tracer compound which, in turn, is captured by strategically placed absorption tubes. The contents of these tubes are then analyzed and the air exchange rate calculated. Multiple tracer sources were placed throughout the trailers with capture tubes usually placed in the central living area and one back bedroom of each home. A secondary method of measuring air exchange, calculated from the exponential decay of CO once heaters were extinguished, was also used. CO decay curves indicated air exchange and pollutant loss within the homes after each burn period. The PFT results give an average air exchange rate during the burn episode and are therefore considered a better indication of true burn-period ventilation than the CO decay data. Both values for each home are presented in the results.

Mean values ± SE mean are quoted in the text. The differences between means were determined from paired t tests and considered to be significant when $p < 0.05$.

Results

Results from the monitoring are presented in table 3 and figure 2. The listed dates are those in which kerosene heaters were in use. Combustion periods represent the time between when the heaters were first ignited to when they were extinguished. The average time respondents used their heaters per day was 4.5 h. Heater use depended mostly upon the home owners' schedules and the outdoor temperatures. The majority of all heaters were used between 4:30 and 11:00 p.m. Respondents started their units indoors 94.1% of the time. Background CO was defined as the CO concentration measured 0.5 h prior to

Table 3. Trailer mobile home monitoring results: CO levels, heater use, air exchange and temperature measurements

Date month-day	Sample home No.	Heater type	Combustion duration, h	Air exchange h^{-1}		CO, ppm		Average CO, ppm		Indoor temperature, °C			Average CO emission rate, μg/kJ[a]
				PFT	CO	back-ground	peak	1 h	8 h	initial	final	average increase	
2-21	1	Omni	3.5	0.345	0.096	0.0	5.0	5.0	3.2	22	26	0.9	12.2
2-22	1	105	4.5	–	0.167	2.0	3.0	3.0	2.7	21	23	0.6	
2-22	1	(convective)	2.5	0.952	0.115	3.8	4.0	4.0	3.6	–	–	–	
2-23	1		7.5	–	–	1.5	3.0	2.9	2.4	–	–	–	
2-6	2	Toyokuni	2.5	2.189	0.138	2.2	37.0	32.2	14.7	26	30	1.8	271.6
2-7	2	(convective)	3.0	0.099	0.186	2.8	40.5	36.2	37.8	23	30	2.4	
2-9	2	(multistage)	10.5	–	0.458	1.0	38.3	36.3	29.4	22	26	0.4	
2-20	2		8.0	1.042	0.330	4.8	50.2	50.0	34.2	25	27	0.3	
2-21	2		1.0	0.607	0.203	5.2	14.8	13.2	8.2	22	26	3.3	
2-22	2		5.5	–	0.105	2.0	41.0	40.0	21.0	19	32	2.3	
2-23	2		8.0	0.789	0.500	2.2	32.5	32.3	23.2	18	24	0.8	
2-24	2		8.0	–	0.371	32.5	33.0	33.0	32.3	24	25	0.2	
2-13	3	Omni	5.0	0.424	0.649	0.0	5.8	5.3	2.2	17	23	1.3	10.5
2-14	3	105	0.5	0.361	0.452	1.0	4.0	4.0	1.9	27	28	1.1	
2-26	3	(convective)	6.0	–	0.664	3.8	4.5	4.3	1.7	20	26	1.1	
2-27	3		5.0	0.539	0.693	0.0	2.0	2.0	0.8	16	23	1.3	
2-28	3		5.0	0.765	1.618	0.0	2.5	2.3	0.8	13	23	0.7	
3-1	3		4.0	0.570	1.617	0.0	3.4	3.3	1.7	22	26	0.8	
2-27	4	Everglow	3.5	0.295	0.760	0.0	3.0	2.0	1.2	14	21	1.9	3.9
2-28	4	(convective)	3.5	0.301	0.342	0.0	1.3	1.3	0.2	15	19	1.1	
3-1	4		3.5	0.577	0.343	0.3	1.9	1.9	1.0	17	20	0.9	
2-17	5	Sanyo (radiant) (multistage)	4.5	0.514	0.448	0.0	17.8	16.0	8.8	18	17	–0.1	263.7
2-6	6	Moon	6.5	0.363	0.064	8.0	9.0	9.0	8.2	21	24	0.6	19.3
2-7	6	lighter	5.5	–	0.083	6.1	8.5	8.3	7.3	20	26	1.2	
2-7	6	(radiant)	4.5	0.379	0.071	5.0	7.7	8.0	6.5	21	24	0.7	
2-8	6		8.5	0.350	0.075	4.8	6.9	7.0	5.8	18	21	0.4	
2-9	6		9.5	–	0.063	3.8	6.0	6.0	5.2	15	23	0.8	
2-27	6		–	0.336	–	3.2	8.0	8.0	5.7	–	–	–	
2-28	6		7.5	0.326	0.094	5.5	7.5	7.3	7.0	18	23	0.7	
3-1	6		8.0	0.312	0.780	5.5	7.0	7.0	2.1	19	26	0.8	
3-2	6		4.5	–	0.731	0.0	1.2	1.1	0.4	17	23	1.5	
2-6	7	Koehring	5.0	0.214	–	0.3	0.3	0.3	0.1	16	19	0.8	56.6
3-1	7	(radiant)	6.0	0.184	0.140	0.0	11.0	10.4	6.9	12	13	0.1	
3-2	7		4.0	–	0.139	2.8	7.3	7.2	4.4	–	–	–	
3-3	7		8.0	–	0.127	4.0	13.8	12.4	9.2	–	–	–	
3-4	7		8.0	–	0.074	13.3	9.3	9.3	7.4	–	–	–	
3-5	7		13.5	–	0.126	3.9	12.4	12.2	7.9	–	–	–	
3-6	7		2.5	–	0.065	4.5	6.1	6.0	4.6	–	–	–	
3-7	7		7.0	–	0.086	2.0	4.2	4.2	3.3	–	–	–	
2-20	8	Alladin	3.0	0.212	0.056	8.0	16.0	16.0	11.8	19	21	0.6	73.3
2-21	8	(radiant)	4.0	0.191	0.099	10.0	29.0	28.3	19.3	21	24	1.0	
2-22	8		17.5	0.424	0.078	6.0	11.5	11.3	9.3	19	24	0.3	
2-23	8		1.0	–	0.102	4.9	10.2	9.0	4.2	19	19	0.0	

– = Data not available due to instrument failure or nonmeasurement.

[a] Reprinted from Mumford et al. [11]. Emission rates are averages based upon pollutant source strength and fuel consumption.

heater start-up. A range of 0–32.5 ppm background was recorded in all trials. High values of > 10 ppm (e.g. the 32.5 ppm measured in home 2 on Feb. 24, table 3) were the result of CO carryover from earlier (same day) combustion periods. While listed in the results, these values did not meet the criteria that all background values be free from kerosene heater emission and were therefore not utilized in any calculations. Average CO concentration from all homes during nonuse days was 1.4 ppm ± 0.3.

Peak CO was determined from the continuous recording of CO concentration in each home. The COED-1 monitors failed to function on several occasions, resulting in some homes producing more data than others. If high readings were seen when no obvious CO sources were present, or if a unit was not able to be calibrated with zero and span gases, the monitor was temporarily removed from the home. The study design was intended to register data for at least 6 days/home with heaters operating. Some potential data were also lost due to extremely warm winter temperatures (highs in the 60s–70s), which eliminated the need for home heating. Peak CO values ranged from 0.3 to 50.2 ppm. Conditions prevailing in some homes were definitely more conducive to CO build up (homes 2, 5, 7 and 8). Residents in homes 2, 7 and 8 routinely used ceiling fans above their heater units while the others did not. None of the families routinely cracked ajar their windows (as manufacturers suggest) during operation. Each home appeared to have its own emission pattern. Home 2 consistently had elevated CO levels, and researchers often found the occupants tired, sleepy and flushed (possible signs of CO exposure). Occupants in this home were given information concerning the effects of CO exposure and how to prevent it during heater use. A peak of 50.2 ppm was once observed in this home.

One-hour maximal CO values of 0.3–49.9 ppm were determined for the homes. This was the average of the values measured 30 min before, during and after the time point yielding the CO peak in each home. Homes 1, 3 and 4 averaged overall less than 5 ppm; homes 6 and 7 averaged 5–10 ppm; homes 5 and 8, 15–20 ppm, and home 2 averaged more than 30 ppm for a 1-hour maximum (fig. 2). Peaks were usually observed at the end of combustion periods. Initial start-ups, while often causing a slight pulse of CO, never approached levels seen at the final time points (except when heater-influenced high background levels existed).

Eight-hour averages were also calculated for each home. Because heaters were rarely on for 8 continuous hours, the measurement was taken to represent an 8-hour period enclosing the 'heater on' period. An example would be that if a heater was in use for 6 h, data from this period as well as 1 h before and 1 h after (a total of 8 h) were used. Data from CO monitors were taken every 15 min throughout the 8-hour period. The average CO concentration from all homes when heaters were on was 7.4 ± 1.4 ppm. As seen in figure 2, homes having elevated 1-hour averages also had the highest 8-hour averages. These values would have been higher if a continuous 8-hour combustion period had been available for sampling (dilution by noncombustion period data). Home 2 had values averaging > 34 ppm. CO was found to steadily increase in every home with the length of the combustion period. Steady states (30-min periods having the same CO levels) were found to occur randomly in only 2 homes. A typical CO emission plot is depicted in figure 3.

Air exchange rates are listed in table 3. Data from the PFT experiments indicated an average air exchange rate in all trials of 0.47 ± 0.05 h^{-1} when heaters were on compared with 0.48 ± 0.05 h^{-1} when units were not burning. Individual exchange data from the homes are presented in table 3 and represent the exchange during the combustion period only. Individual values ranged from 0.18 to 2.19 exchanges/h. Values from home 2 varied widely, which may have been due to the opening of windows and doors or the failure of this family to terminate PFT sampling at the conclusion of a burn period. Air exchange rates based upon the CO decay method indicated that this technique generally gave lower values as compared with the PFT technique (except in the data from home 3).

Initial and final indoor temperatures (table 3) indicate temperature rise as a function of factors such as air exchange, combustion length, radiant losses of the home and the BTU (British thermal unit) factor of the heater. Average indoor temperatures rose 1.06 °C/h of heater use. This value is biased of course, as the heaters had to offset falling outdoor temperatures during these measurements. The average relative humidity in each home during heater use was 62.0 ± 2.4%.

CO emission rates listed in table 3 have previously been reported [11]. These are average pollutant emission rates based upon a simplified model by Traynor et al. [12]. A range of 3.9–271.6 μg/kJ CO was observed from the 8 heaters. Radiant heaters 6, 7 and 8 were found to produce higher CO emission rates (19.3–73.3 μg/kJ) as compared with all other heaters except for the dual combustion units in homes 2 (convective) and 5 (radiant). These emitted 271.6 and 263.7 μg/kJ CO, respectively.

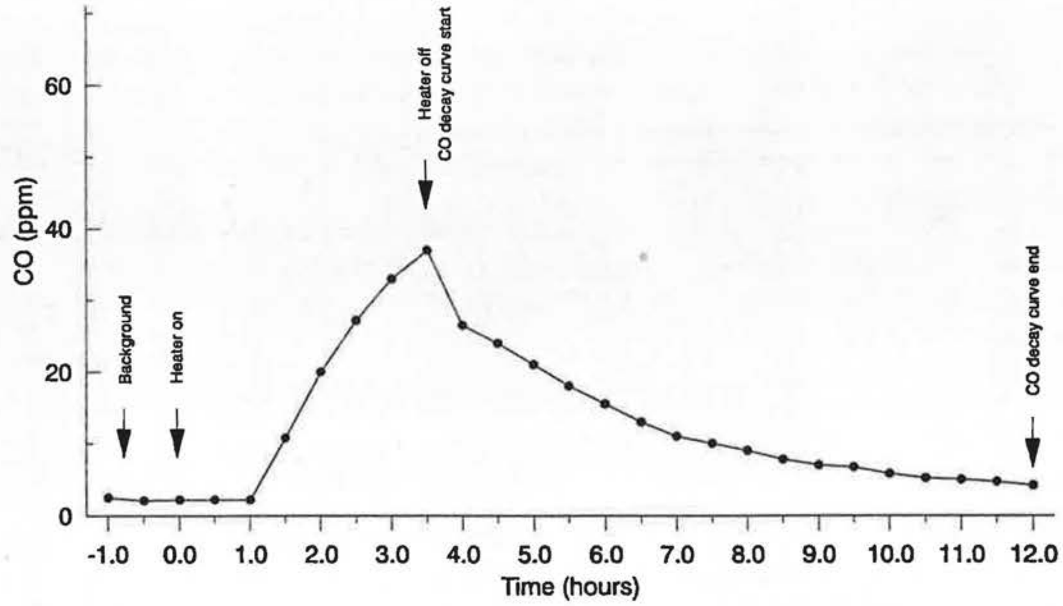

Fig. 3. Continuous level of CO monitored within home 2 at ignition, extinguishing, and during the decay period. Points at which CO decay curve measurements would begin and end are marked.

Discussion

The heaters utilized in this study registered typical percent BTU/h values compared with listed manufacturers' ratings (66–83%). These values agree with those reported by others [3, 6]. One heater (home 7) exceeded its rating by 67%. These results were based upon fuel consumption, and this heater was found to range between 1.04 and 3.21 times the expected BTU/h daily. This heater did not exhibit signs of poor burning (i.e. smoking, flickering) and no reason for this apparent over-output has been found. Homes selected were typical of those currently being manufactured in the US. Total air volume in these homes (based upon ceiling heights of 2.5 m) would be from 150 to 255 m^3. PFT-based air exchange rates were typically below 0.5 exchanges h^{-1}, which compares to rates of 0.5–1.5 found in most US homes [9]. Structures having air exchanges below 0.5 h^{-1} are viewed as energy efficient [8].

No structured comparisons between various heater types and manufacture were planned at the beginning of this study although an even distribution of types was an objective in home selection. There are known differences in emissions from radiant, convective and multistage (combination) heater designs [2–7]. Homes in this study with multistage combustion chamber (2, 5) and radiant heaters (6, 7 and 8) were found to have higher overall CO levels when compared with homes with single stage convective heaters (1, 3 and 4) (comparison of 8-hour averages, $p < 0.05$). Reported comparisons of radiant and convective heaters have shown similar differences [3, 5, 7, 9]; however, one study has reported no differences between heater types [2]. In the present study, the homes having multistage elements (2, 5) yielded some of the higher CO levels. These heaters, designed to decrease pollutant emissions, have been shown to typically yield lower CO emission rates than the other two heater types. Emission values of 2–4 times less (convective) and 100 times less (radiant) have been described [7]. Emission rates are dependent upon BTU output, age and height of the wick and other operating parameters. The owners of both these multistage heaters had installed new wicks at the start of the heating season and always operated their wicks in the 'high' positions. No reason can be cited at this time for the apparently high CO levels from these heaters.

CO levels in homes 1, 3 and 4 averaged well below the primary US air standard for CO (9 ppm for an 8-hour exposure) but above their respective background levels. Homes 5–7 had 8-hour averages near the 9-ppm standard and homes 2 and 8 averaged clearly above this level. Only home 2 registered CO levels exceeding the 1-hour US standard of 35 ppm. In fact, this home exceeded the standard in 4 of 8 trials with 3 other trials within 2.7 ppm for 1-hour averages.

There are few reported data regarding kerosene heaters in mobile homes, thus making comparisons in this study difficult. More frequently, tests in chambers and larger homes have been discussed in the literature. Most CO levels found in this study would appear to be equal to or higher than those reported in similar-sized residences [4–6]. While ceiling fans were utilized in some of the homes, adequate mixing of ambient air could not be assumed. Most home owners kept interior doors (bedrooms) closed, further reducing air movement within the homes. It is likely in the present study that a much smaller space was monitored than that designated by the whole-house dimensions. This consisted of the central interior of the home (kitchen/living room), where the occupants spent the majority of their time. This microenvironment of 30–40 m^3 would then be more representative of most of the chamber work described by others. Tests conducted in a 27-m^3 chamber (0.4 exchanges h^{-1}) indicated that CO levels above 12 and 3 ppm for radiant and convective heater designs, respectively, could be expected from 1-hour combustions [3]. Ventilation tests performed in a 34-m^3 chamber [9] revealed that from air exchange rates of 0.5 h^{-1}, CO concentrations from a radiant heater could be expected to be above 15 ppm, while 7 ppm would be reached by a convective heater. This agrees well with our findings.

Simplified CO emission rates were found in the range of those reported elsewhere [2, 3, 7, 12]. Radiant heaters had the highest CO emission rates with the exception of home 2. The high value seen with this convective heater (271.6 μg/kJ) is typical of some low-efficiency radiant designs. The 263.7 μg/kJ CO emission rate observed in home 5 is based upon a single combustion episode. Even so, it would appear that the two multistage heaters tested (2, 5) emitted significantly more CO as compared with single-stage radiant or convective designs in this study.

This study supports the theory that many consumers may be failing to take adequate precautions when using unvented kerosene space heaters. High CO levels could result when an oversized heater (excess BTU/h in relation to room size) is not ventilated accordingly. Published studies have already noted negative effects on humans exposed to CO emissions from heaters [13, 14]. This problem is likely to become more pronounced as heaters are being used in a greater number of mobile homes which are becoming more and more energy efficient [1]. Consumer education should be undertaken to reduce this potential health risk.

Acknowledgements

The authors wish to thank Lance Brooks, Nancy Mayer and Bob Burton for their technical contributions to this study. Although the research described in this article has been supported by the US Environmental Protection Agency (through contract 68-02-4456 to Environmental Health Research and Testing, Inc.), it does not necessarily reflect the views of the Agency, and no official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendations for use.

References

1 Barnes J, Holland P, Mihlmester P: Population and usage of unvented kerosene space heaters. EPA Publication EPA-600/7-90-004. Research Triangle Park, US Environmental Protection Agency, 1990, pp 1–68.
2 Woodring R, Duffy T, Davis J, Bechtold R: Measurements of combustion product emission factors of unvented kerosene heaters. Am Ind Hyg Assoc J 1985;46:350–356.
3 Traynor G, Allen J, Apte M, Girman J, Hollowell C: Pollutant emissions from portable kerosene-fired space heaters. Environ Sci Technol 1983;17:369–371.
4 Ritchie I, Oatman L: Residential air pollution from kerosene heaters. J Air Pollut Control Assoc 1983;33:879–881.
5 Traynor G, Apte M, Carruthers A, Dillworth J, Grimrud D, Thompson W: Indoor air pollution and inter-room pollutant transport due to unvented kerosene-fired space heaters. Environ Int 1987;13:159–166.
6 Traynor G, Girman J, Apte M, Dillworth J, White P: Indoor air pollution due to emissions from unvented gas-fired space heaters. J Air Pollut Control Assoc 1985;35:231–237.
7 Lionel T, Martin R, Brown N: A comparative study of combustion in kerosene heaters. Environ Sci Technol 1986;20:78–85.
8 Moschandreas D, Zabransky J: Spatial variations of carbon monoxide and oxides of nitrogen concentrations inside residences. Environ Int 1982;8:177–183.
9 Leaderer B: Air pollutant emissions from kerosene space heaters. Science 1982;218:1113–1115.
10 Dietz R, Goodrich R, Cote E, Wieser R: Detailed description and performance of a passive perfluorocarbon tracer system for building ventilation and air exchange measurements. ASTM STP 904. Philadelphia, American Society for Testing and Materials, 1986, pp 203–264.
11 Mumford J, Williams R, Walsh D, Burton R, Svendsgaard D, Chuang J, Houk V, Lewtas J: Indoor air pollutants from unvented kerosene heater emissions in mobile homes: Studies on particles, semivolatile organics, carbon monoxide, and mutagenicity. Environ Sci Technol 1991;25:1732–1738.
12 Traynor G, Apte M, Sokol H: Selected Organic Pollutant Emissions from Unvented Space Heaters. Environ Sci Technol 1990;24:1265–1270.
13 O'Sullivan B: Carbon monoxide poisoning in an infant exposed to a kerosene heater. J Pediatr 1983;103:249–251.
14 Cooper K, Alberti R: Effect of kerosene heater emissions on indoor air quality and pulmonary function. Am Rev Respir Dis 1984;129:629–631.