

A Study of Indoor Air Quality

Willard A. Wade III, William A. Cote, and John E. Yocom
TRC—The Research Corporation of New England

As part of a larger program to investigate indoor sources of air pollution, an indoor/outdoor sampling program was carried out for NO, NO₂, and CO in four private houses which had gas stoves. The four houses chosen for study represented different surrounding land use, life styles, and house age and layout. The pollutant gases were measured essentially simultaneously at three indoor locations and one outdoor location. The results of the program showed that indoor levels of NO and NO₂ are directly related to stove use in the homes tested. Furthermore, these stoves often produced more NO₂ than NO. In some instances, the levels of NO₂ and CO in the kitchen exceeded the air quality standards for these pollutants if such outdoor standards were to be applied to indoors and the data for the sampling periods were typical of an entire year. A diffusion experiment conducted in one of the houses showed that the half-life for NO₂ was less than one-third that for either NO or CO. Oxidation of NO to NO₂ (based upon comparing the half-life of NO to CO) does not appear to occur to a significant degree indoors.

Earlier work on indoor/outdoor air quality relationships showed that indoor quality is a complex function of outdoor pollutant concentrations, building permeability, meteorological conditions, ventilation system design, and indoor generation of pollutants.^{1,2} While more work is needed in establishing the specific effect of each of these factors on indoor air quality, the one factor of those listed which is least understood and which will assume greater importance as outdoor air quality improves, is indoor generation of air contaminants.

This paper* describes the results of the field monitoring program which consisted of measurements of nitrogen dioxide (NO₂), nitric oxide (NO), and carbon monoxide (CO) inside and outside of four residences each with a gas stove used for cooking. Approximately two weeks of monitoring were performed at each of three structures during the spring and summer of 1973 and the fall and winter of 1973-1974. Two of the structures were common to both sampling periods and one other structure was sampled during each period giving a total of four separate structures sampled in the overall program.

* The work upon which this publication is based was performed pursuant to Contract Number 68-02-0745 of the U.S. Environmental Protection Agency.

Procedures

Structure Selection

The field measurement program was designed specifically to evaluate the effect of gas cooking appliances on indoor pollutant levels. While gas stoves are certainly not the only source of indoor pollutants, they are a readily identifiable source which is in widespread use. The major pollutants of interest that are emitted from gas appliances are nitrogen dioxide (NO₂), nitric oxide (NO), and carbon monoxide (CO). Four structures were selected for the measurement program. These residences represent the wide differences in land use, house type and layout, gas appliance age, and life styles which are desirable in an exploratory study such as this. Table I summarizes the characteristics of the residences where the sampling was conducted.

Measurement System

The objective of the field measurement program dictated that pollutant concentrations be determined at several points within the structure being sampled. A simultaneous measurement of the ambient outdoor concentration of each pollutant measured is also desirable to act as a reference and to gauge the possible influence of outdoor concentration on the levels measured indoors. Locating individual monitors at each sampling point would represent a substantial equipment investment and would result in multiple servicing and space requirements not to mention data reduction problems, and lack of confidence in the comparability of data from point to point if individual instruments were used.

In order to measure pollutant concentrations at multiple locations and yet conserve the amount of instrumentation and manpower required to obtain these data, TRC designed and built a unique measurement system as shown in Figure 1. Four sampling locations were chosen for sampling, three indoor and one outside. The major components of the system are four continuously purged sampling lines with an integrating chamber, solenoid valves, Bendix chemiluminescent NO/NO₂ analyzer, Intertech non-dispersive infrared analyzer, CO and NO/NO₂ calibration systems, strip chart recorders, and electronic sequencer. The system design acknowledged the need for:

1. Continuous, uninterrupted operation with only periodic service.
2. Frequent automatic and manual calibration checks.

Table I. Characteristics of field program residences.

Characteristics	House No. 1	House No. 2	House No. 3	House No. 4
Type	Split-level, large, centrally located and well ventilated kitchen	Two-story, medium size, centrally located and well ventilated kitchen	Two-story apartment with small, unventilated kitchen	Single story, small ranch style, kitchen open to other areas of house
Size, ft ²	2000	1500	1000	1500
Age, * yr	8	40	2	14
Location	Suburban development 1/2 mi from inter-state highway	Urban residential area on local artery	Suburban community	Suburban development near local main road
Gas appliances	Stove and heating system	Stove	Stove	Stove and heating system
Occupants	Two adults and two teenage children	Single adult	Two adults and two preschool children	Two adults and two children
Sampling periods	May 1973 November 1973	May-June 1973	June-July 1973 November-December 1973	January-February 1974

* For both residence and gas appliances.

3. Ability to be readily moved from one location to another.
4. Small space requirement within the sampled structure.

As shown schematically in Figure 1, the sample stream from each of the four locations is piped to a central location through 15 meters of 4.8 mm I.D. Teflon tubing at a rate of approximately 9.5 lpm. This is equivalent to a retention time in the tubing of approximately 2 sec. Each sample stream is then drawn through an individual 500 ml glass integrating chamber, through a diaphragm pump, and then vented. This arrangement provides continuous purging of the sampling lines. From the integrating chamber for each station, two small sample streams are drawn to the NO/NO₂ analyzer and the CO analyzer. Solenoid valves on each of these sample lines, controlled by the electronic sequencer, permit each station's sample to be drawn into the detectors for a 5 min period. A complete sampling cycle requires 20 min and three 5 min samples are obtained per station per hour. A two pen recorder was used for the NO and NO₂ output of the chemiluminescent analyzer and a separate pen unit for recording the CO output.

Calibration of the chemiluminescent NO/NO₂ analyzer was accomplished with a dynamic dilution module. A wide range of concentrations of NO and NO₂ can be generated with a bottle of NO calibration gas attached to this unit. Room air that is used to dilute the NO calibration gas to the desired concentration is first treated to remove any NO or NO₂. Various concentrations of nitrogen dioxide can also

be made in this module by using an ozone generator.

The calibration of the non-dispersive infrared (NDIR) CO detector was accomplished with zero gas and 17.0 ppm CO calibration gas which was introduced into the NDIR once every 8 hr.

Field Operations

The sampling equipment and auxiliary calibration devices were installed in an unobtrusive location in each house so as not to interfere with the residents' activities. Teflon sample lines were run from the equipment to four sampling locations:

Designation	Spring-Summer	Fall-Winter
Station 1	Kitchen-over stove (except House No. 1)	Kitchen-over stove
Station 1A		Kitchen-approx. 1 m from stove
Station 2	Living room	Living room
Station 3	Bedroom	Bedroom (except House No. 4)
Station 4	Outside of structure	Outside of structure

The sample intake for each station was placed in the breathing zone, between 4½ and 6 ft above the floor. The sample intake for Station 1, in the kitchen, was placed directly over the stove except at House No. 1 during the spring-summer sampling period. For this sampling period at House No. 1, the sample intake was placed approximately 3 ft from the stove. This location corresponds to Station 1A for the fall-winter sampling period when it was possible to locate Station 1 directly above the stove. The data from Station 1 were used to determine the concentrations of NO₂, NO, and CO at the source, the stove. Comparison of these data with those obtained from other stations showed the behavior of the pollutants as they diffused through the structure and the effect of the source on indoor air quality within the structure.

Station 1A (placed approximately 1 m from the stove) was used in the fall-winter sampling period to determine NO₂, NO, and CO concentrations within the kitchen, other than directly above the stove. These data were intended to show the behavior of the pollutants in the vicinity of the stove as they diffused from the source throughout the structure.

Station 2 was placed in the living room away from windows, doors, and air conditioners. Station 2 was used (alternately with station 3) for about half of the fall-winter sampling period at each house. Comparison of the data ob-

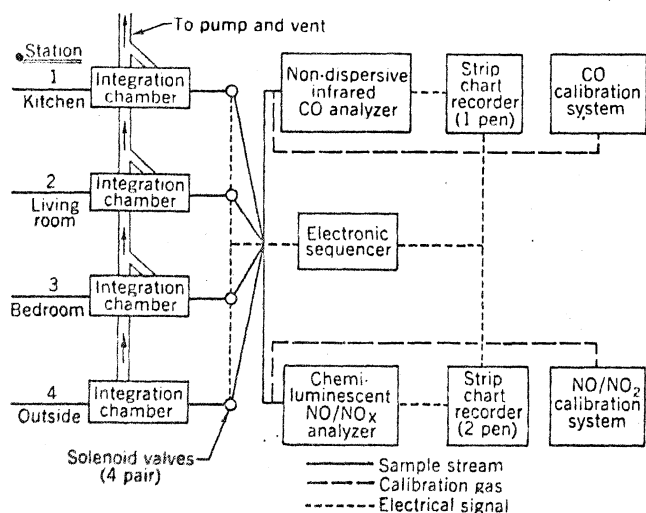


Figure 1. NO, NO₂, and CO sampling and measurement system.

tained from Stations 1, 1A, and 2 was intended to show the characteristic changes in indoor air quality in an area on the same level as the source, at Station 1.

Station 3 was placed in a bedroom to provide data to determine the relationship between concentrations in the kitchen and more remote areas within the structure, particularly where people spend 8 hr sleeping. As noted earlier, this sampling location was alternated with Station 2 during the fall-winter sampling period at each house with the exception of House No. 4. At this house, it was not possible to sample at Station 3 because of the inconvenience it would have caused the residents.

Station 4 was placed outside the structure to provide reference measurements for the pollutants measured indoors. Measurement of the outdoor pollutant concentrations was necessary to determine if they control the indoor concentration by infiltration. The contribution of the stove to indoor air quality was determined by comparing the outdoor with the indoor concentrations.

A form was developed for use by the housewife or other person using the kitchen to record pertinent data on stove use. The total number of minutes of oven and burner use were tabulated for each day of sampling. These forms provided a record of the level of use and the respective time of use of the stove that was useful for interpretation of the sampling data.

The sampling equipment was serviced at least every other day. The service included calibration and functional checks of the sampling equipment. Adjustments were made as necessary. The residents assisted by frequently recording time and events directly on the strip charts and alerting TRC to any possible malfunction that occurred.

Data Summarization

The considerable amount of data generated in this program precluded manual examination of the data in its entirety. Semiautomatic analog to digital conversion equipment and computer programs were used to reduce the labor in the data evaluation process.

To develop diurnal trends in air quality at the three indoor and outdoor sampling locations and provide some degree of smoothing, we accumulated 5 min bits into 2 hr averages. On a few occasions, less than 6 (the maximum possible number) 5 min bits of data were available for each 2 hr period since some data were lost during instrument servicing periods and during periods of instrument malfunctions. Nevertheless, we defined the 2 hr average as the average of all 5 min bits in that period even though less than 6 bits might be available.

In calculating daily averages, we gave equal weight to all 2 hr averages. However, a daily average was not computed for any day which had one or more 2 hr average values missing for all stations.

In addition to the above summaries, we developed a number of summaries of the diurnal pattern of NO₂ for several of the house-pollutant-season combinations in terms of a "composite day." Here we determined the average concentration for each 2 hr time interval for all those days for which 12 valid 2 hr average values were available.

Frequency distributions for NO, NO₂, and CO data were compiled from all the 5 min data at each location for each house in order to assess the frequency of exposure to the range of concentrations measured during the field program. In constructing these distribution curves, we used all 5 min data and assumed that any loss of data during a sampling period was more or less randomly distributed by time of day. While these frequency distributions may not be statistically valid because of the loss of a certain amount of data, we believe that they provide useful information.

In addition to the above data presentations, we plotted

graphs showing the time history of NO₂, NO, and CO for brief episodes in order to show the direct dependence of indoor concentrations on stove usage.

Results and Discussion

The results presented in this section represent a portion of the findings of the complete study and have been selected to show some of the more interesting findings. Those wishing to examine the results of the entire program are directed to the Final Report to EPA.³

House No. 1

Table II summarizes the average data from House No. 1 for NO₂, NO, and CO concentrations and indoor/outdoor ratios, as well as stove use. As stated earlier, this was a large suburban split level house. The higher concentrations of all pollutant gases in the kitchen as compared with the other rooms show that the stove is a significant source of the pollutants measured. In addition, there is some indication that stove use correlates with kitchen concentrations, although outdoor concentrations and season with its effect on the permeability of the house complicate this relationship. Note the comparative levels of NO₂ at Station 1A in the spring and first half of the fall and the corresponding stove use levels. Note also from Table II that NO₂ and NO were formed in the kitchen in roughly the same amounts in the spring and second half of the fall. In the first half of the fall, relatively less NO₂ than NO was produced.

Another way to show the effect of stove use on indoor air quality is to show a time history graph of pollutant concentrations in the house together with stove use data. Figure 2 is a graph of 2 hr average NO₂ levels for a typical four day period at House No. 1. This graph shows the rapid response of NO₂ levels to stove use, followed quickly by the response at the other two indoor locations. The oven, in particular, seems to have the greatest influence on the indoor NO₂ concentrations. Examination of the 5 min data showed that the generation of NO₂ by the oven is greatest during the initial oven startup. Flame re-ignition by the thermostat to maintain oven temperature creates momentary peaks that are generally less than those reached during the initial warm-up. Average NO₂ concentrations in the kitchen during inactive periods were slightly greater than NO₂ levels at the other two indoor locations which closely approximated the outdoor NO₂ concentrations. The higher kitchen concentrations are undoubtedly caused by the stove's pilot lights.

A time history for NO was developed for the same period as that shown in Figure 2 for NO₂. While this graph is not presented here, it was basically similar to that for NO₂. The similarity in trace at all sampling points showed that NO and NO₂ are formed together by the stove and that little if any NO is oxidized to NO₂ inside the house.

Figures 3 and 4 show the diurnal pattern of NO₂ data for the spring and first half of the fall periods respectively. These curves were based on a "composite day" as described earlier. The difference in basic patterns for the two periods is undoubtedly caused by different schedules of stove use. Note that in the spring the levels of NO₂ in the rooms away from the kitchen are considerably below the kitchen curve, while in the fall the levels in all rooms are bunched closely together. We attribute this to the house being more tightly closed during the colder months.

House No. 2

This house was occupied by a young bachelor who made only infrequent use of the stove. The data on NO₂, NO, and CO levels reflected the low levels of stove use in that the in-

Table II. House No. 1. Summary of NO₂, NO, and CO concentrations.^a Spring and Fall, 1973.

Season and data category	Sampling Location					Average stove use—min/day		
	1 Kitchen above stove	1A Kitchen, 1 m from stove	2 Living room	3 Bedroom	4 Outside	Oven	Burners	Total
Spring 1973								
NO ₂ Concentrations, μg/m ³		100	61	52	44	87	133	220
NO ₂ Indoor/outdoor ratios		2.27	1.39	1.18				
NO Concentrations, μg/m ³		102	64	65	26	87	133	220
NO Indoor/outdoor ratios		3.92	2.46	2.50				
CO Concentrations, μg/m ³		4490	4070	4170	3480	76	122	198
CO Indoor/outdoor ratios		1.29	1.17	1.20				
Fall 1973 (First half)								
NO ₂ Concentrations, μg/m ³	67	60	55		50	70	64	134
NO ₂ Indoor/outdoor ratios	1.34	1.20	1.10					
NO Concentrations, μg/m ³	136	134	94		63	70	64	134
NO Indoor/outdoor ratios	2.16	2.13	1.49					
CO Concentrations, μg/m ³	4190	3520	3230		1670	46	60	106
CO Indoor/outdoor ratios	2.51	2.11	1.93					
Fall 1973 (Second half)								
NO ₂ Concentrations, μg/m ³	110	67		49	46			
NO ₂ Indoor/outdoor ratios	2.39	1.46		1.07				
NO Concentrations, μg/m ³	134	131		102	65			
NO Indoor/outdoor ratios	2.06	2.02		1.57				
CO Concentrations, μg/m ³	4790	4210		3830	2310			
CO Indoor/outdoor ratios	2.07	1.82		1.66				

^aAverage concentrations are based on daily averages for those days in which 12 valid 2-hour averages were obtained.

^bStove use data not available for second half of fall sampling period.

door levels of these pollutants were essentially coincident with those outside. These results showed that all three pollutants penetrated the house to the same degree.

The relatively infrequent use of the stove in this house during our measurement program presented us with the opportunity to conduct a diffusion experiment with this appliance. This experiment was intended to give us some insight into the behavior of the pollutants within a residential structure that was free from disturbance or interference.

The five burners and oven were turned on simultaneously at maximum flame for 71 min. At this point the pollutant concentrations approached full scale on the recorders, and the stove was turned off. The sequential sampling at the four locations for NO₂, NO, and CO continued until their respective concentrations decayed to their pre-experiment levels.

Table III shows the peak values measured as the burners were shut off. The living room and bedroom concentrations are expressed as percentages of the peak kitchen concentration. Note that the peak value for NO₂ in the bedroom was 55% of the kitchen value while the peak CO value in the bedroom was 73% of the kitchen value. Assuming that CO is unreactive and disappears only through dilution, it was therefore apparent that NO₂ is lost through dilution and other mechanisms. To confirm this, we determined the decay rate for each of the pollutants by analyzing the 5 min data for each. Carbon monoxide exhibited its expected stability in having the longest half-life of the three pollutants, 2.1 hr. The decay in CO can be considered as representing loss through dilution only. Nitric oxide had a half-life of 1.8 hr. While this half-life is somewhat less than CO, the loss of NO through reaction (oxidation to NO₂) and other mechanisms does not appear to be significant. Nitrogen dioxide

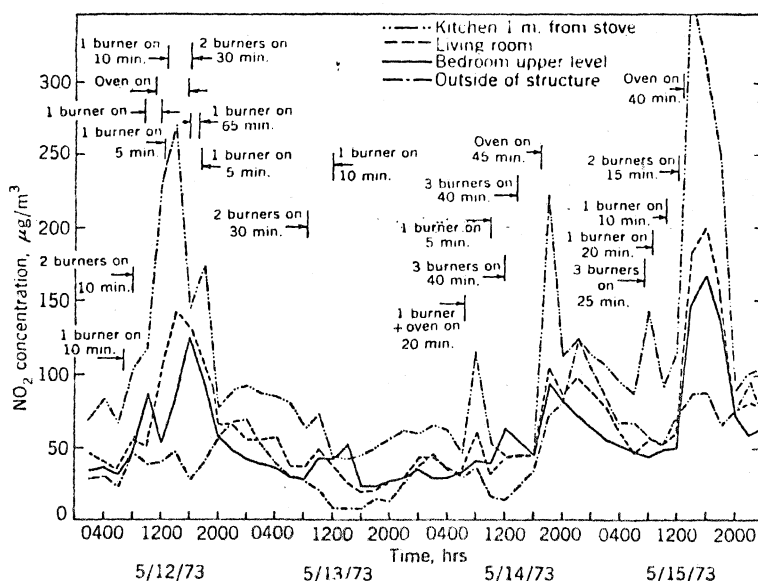


Figure 2. A time history of NO₂ concentrations (2 hr averages) at House No. 1.

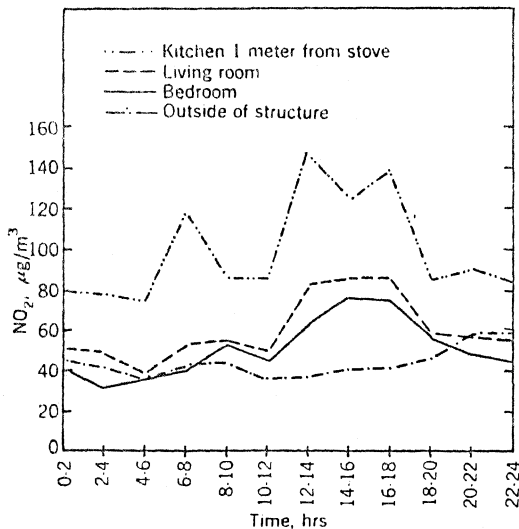


Figure 3. Diurnal indoor/outdoor pattern for NO_2 : House No. 1, spring-summer 1973 (composite day based on 6 days of data).

had a substantially lower half-life of 0.6 hr. Clearly, this behavior of NO_2 suggests its loss through reaction, aerosol formation and other mechanisms. The relatively high moisture content in the kitchens with gas stoves (boiling of water and water vapor from the burning of natural gas) may enhance some of these mechanisms.

Table III. Peak concentrations of oxides of nitrogen and carbon monoxide during diffusion experiments at House A-2.

Parameter	Kitchen	Living room	Bedroom
NO_2 , $\mu\text{g}/\text{m}^3$	1,450	900 (62%) ^a	790 (55%) ^a
NO , $\mu\text{g}/\text{m}^3$	2,030	1,560 (77%) ^a	1,400 (69%) ^a
CO , $\mu\text{g}/\text{m}^3$	12,800	10,400 (81%) ^a	9,300 (73%) ^a

^aPercent of peak value measured in kitchen.

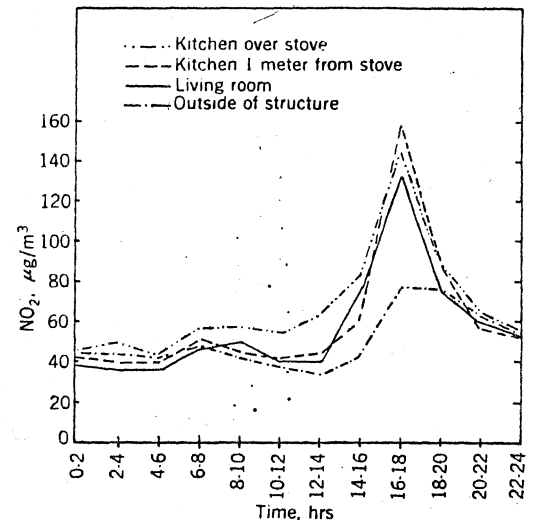


Figure 4. Diurnal indoor/outdoor pattern for NO_2 : House No. 1, fall 1973 (first half) (composite day based on 7 days of data).

Table IV. House No. 3. Summary of average NO_2 , NO , and CO concentrations.^a Spring and Fall 1973.

Season and data category	Sampling Location					Average stove use — min/day		
	1 Kitchen above stove	1A Kitchen, 1 m from stove	2 Living room	3 Bedroom	4 Outside	Oven	Burners	Total
Spring 1973								
NO_2 Concentration, $\mu\text{g}/\text{m}^3$	114		75	58	51	0	11	11
NO_2 Indoor/outdoor ratios	2.23		1.47	1.14				
NO Concentrations, $\mu\text{g}/\text{m}^3$	53		42	34	21	0	11	11
NO Indoor/outdoor ratios	2.52		2.00	1.62				
CO Concentrations, $\mu\text{g}/\text{m}^3$	4310		3210	2680	2230	14	23	37
CO Indoor/outdoor ratios	1.93		1.44	1.20				
Fall 1973 (First Half)^b								
NO_2 Concentrations, $\mu\text{g}/\text{m}^3$	53	47	28		35	0	20	20
NO_2 Indoor/outdoor ratios	1.51	1.34	0.80					
NO Concentrations, $\mu\text{g}/\text{m}^3$	111	95	42		40	0	20	20
NO Indoor/outdoor ratios	2.78	2.38	1.05					
CO Concentrations, $\mu\text{g}/\text{m}^3$	7820	6420	5070		3380	11	55	66
CO Indoor/outdoor ratios	2.31	1.90	1.50					
Fall 1973 (Second Half)								
NO_2 Concentrations, $\mu\text{g}/\text{m}^3$	180	140		70	32	25	49	74
NO_2 Indoor/outdoor ratios	5.62	4.38		2.19				
NO Concentrations, $\mu\text{g}/\text{m}^3$	111	101		64	20	25	49	74
NO Indoor/outdoor ratios	5.55	5.05		3.20				
CO Concentrations, $\mu\text{g}/\text{m}^3$	7130	6620		5500	2500	70	45	115
CO Indoor/outdoor ratios	2.85	2.65		2.20				

^aAverage concentrations are based on daily averages for those days in which 12 valid 2 hr averages were obtained.

^bAverage NO_2 and NO concentrations during this sub period are based on data for only one day.

During the second half of the fall sampling period the average NO₂ concentrations in the kitchen over the stove was 180 µg/m³ while that displaced from the stove by 1 m was 140 µg/m³. Note also that indoor NO₂ concentrations are considerably greater than those for NO.

The data for this sampling period appear to show the shorter half-life of NO₂ as compared with NO and CO. If we assume that the outdoor concentrations can be considered as "background" to the indoor concentrations and that the difference between indoor and outdoor concentrations represents the contributions of the stove at each sampling point, the following "net" indoor concentrations can be listed:

	Net Indoor Concentrations µg/m ³		
	Station 1	Station 1A	Station 3
NO ₂	148	108	38
NO	91	81	44
CO	4630	4120	3000

An indication of the decay of pollutant gas can be represented by the ratio of the concentrations at any of the sampling points to the maximum kitchen value (Station 1 over the stove). These ratios are listed as follows:

	Ratio C _x /C ₁		
	Station 1	Station 1A	Station 3
NO ₂	1.0	.73	.26
NO	1.0	.89	.48
CO	1.0	.89	.64

The above ratios show that NO₂ disappears much faster than either NO or CO.

House No. 4

Because of the low level of stove use at House No. 2, we decided not to sample at this house after the spring program and therefore selected House No. 4 for winter sampling. As stated earlier, this was a small ranch style house with the kitchen open to the other areas of the house.

Table V summarizes the indoor/outdoor air quality and stove use data for House No. 4. In this house, we measured the highest pollutant concentrations in any of the houses tested. If outdoor ambient air quality standards are applicable to the indoor environment, the 8 hr standard for CO (10,000 µg/m³) was exceeded in the kitchen of this house. In comparing the results from this house with House No. 1, note that in Table II, the amount of stove use associated with the NO₂ and NO was similar during the first part of the fall period to that for House No. 4. Yet concentrations of NO₂ and NO in the kitchen of House No. 4 (Stations 1 and 1A) were 2 to 3 times those at House No. 1. The higher concentrations in House No. 4 as compared to House No. 1

are attributable to the decreased size of the house and the increased tightness of House No. 4 in January and February as opposed to House No. 1 in the fall.

Without going through the same exercise used with House No. 3 to demonstrate the more rapid decay of NO₂ as compared with NO and CO, it is apparent that this is the case merely by making a rough comparison of the indoor/outdoor ratios in the various rooms.

Figures 5, 6, and 7 are presented to show the patterns of NO₂, NO, and CO within the house. The NO₂ and NO graphs are for coincident periods and the CO graph is for an earlier period. Note the sharp spike on the NO₂ graph soon after the oven was turned on. While the spike occurs at this same point on the NO graph, it is not as pronounced. This confirms laboratory experiments carried out as part of this overall program which showed that the oven tends to generate relatively more NO₂ than the burners.³ The relative position of the curves for Station 1A (Kitchen,

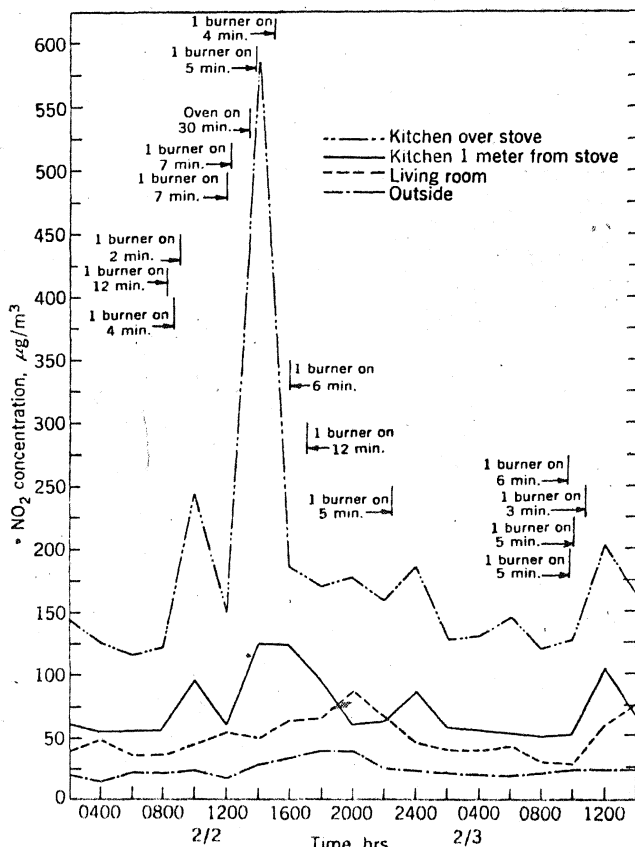


Figure 5. House No. 4: A time history of NO₂ concentrations, 2 hr averages, winter 1974.

Table V. House No. 4. Summary of NO₂, NO, and CO concentrations.^a Winter (January-February) 1974.

Data category	Sampling location				Average stove use—min/day		
	1 Kitchen above stove	1A Kitchen 1 m from stove	2 Living room	4 Outside	Oven	Burners	Total
NO ₂ Concentrations, µg/m ³	213	120	71	39	66	73	139
NO ₂ Indoor/outdoor ratios	5.46	3.08	1.82				
NO Concentrations, µg/m ³	305	229	156	19	66	73	139
NO Indoor/outdoor ratios	16.1	12.1	8.2				
CO Concentrations, µg/m ³	9070	9000	8190	2410	85	116	201
CO Indoor/outdoor ratios	3.76	3.73	3.40				

^aAverage concentrations are based on daily averages for those days in which 12 valid 2 hr averages were obtained.

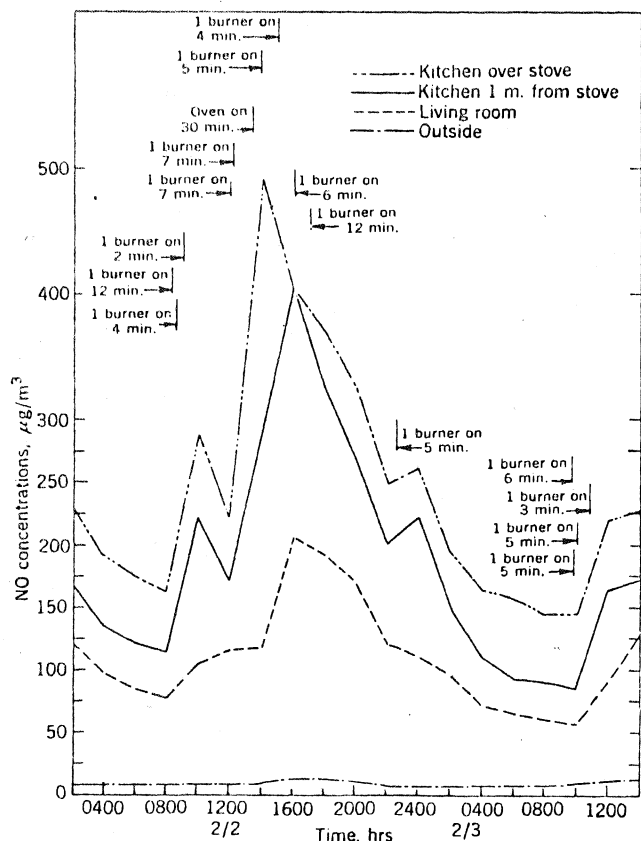


Figure 6. House No. 4: A time history of NO concentrations, 2 hr averages, winter 1974.

1 m away from the stove) and the living room again shows that NO₂ decays more rapidly than either NO or CO.

Conclusions

As was shown in the results of our earlier indoor/outdoor program,¹ the use of a sequential multiple-point measurement system coupled with centrally located analyzers was both a valid and efficient means of near-simultaneous measurement of pollutant profiles inside and outside of structures. This method permitted the detection of both short term fluctuation of pollutant concentrations at a number of sampling locations and small concentration differences from point to point without using separate analyzers for each sampling location.

The salient conclusions we have drawn from the data collected in this program are:

1. Emissions from gas stoves contribute NO₂, NO, and CO to indoor atmosphere of houses where such stoves are used. Kitchen concentrations of these gases responded rapidly to stove use, and for a given house during a given season there was a rough correlation between average NO₂ concentrations and average stove use.
2. NO₂ and NO were produced in roughly equal amounts by the stoves in the homes where testing was conducted. Indoor concentrations of these pollutants were invariably higher than those outside.
3. Normal stove operations frequently resulted in NO₂ concentrations in the kitchens which averaged over 100 µg/m³ over a 2 wk sampling period.
4. Comparison of samplings carried out in the spring-summer of 1973 and the fall-winter of 1973-74 showed that the more closed up mode of the house in the colder weather produced more uniform concentrations within the various rooms of the house as compared with the warmer months.

5. A diffusion experiment conducted in one of the houses showed that the half-life of NO₂ was only 1/3 of that for CO and NO, indicating that NO₂ decays through reaction or absorption in addition to normal dilution from air exchange. This effect was observed in some of the other houses by comparing the relative concentrations of NO₂ and the other pollutants in various parts of the house.

Acknowledgment

The authors wish to express their thanks to Elbert Tabor and Robert Burton of EPA for their guidance and suggestions throughout the program, and to the owners of the homes where sampling was done for their cooperation and patience.

References

1. J. E. Yocom, W. L. Clink, and W. A. Cote, "Indoor/outdoor air quality relationships," *J. Air Poll. Control Assoc.* 21: 5 251 (1971).
2. J. E. Yocom, W. A. Cote, and W. L. Clink, "Measurement of Air Pollution Penetration into Building Interiors," Presented at 17th Annual ISA Analysis Instrumentation Symposium, April 19-21, 1974, Houston, Texas, published in the Proceedings: *Analysis Instrumentation*, Vol. 9—ISA, Pittsburgh, PA.
3. W. A. Wade, III, W. A. Cote, and J. E. Yocom, "A Study of Indoor Air Quality," Final Report, Contract 68-02-0745, Publication No. EPA 650/4-74-042, Environmental Protection Agency, Research Triangle Park, NC Sept. 1974.

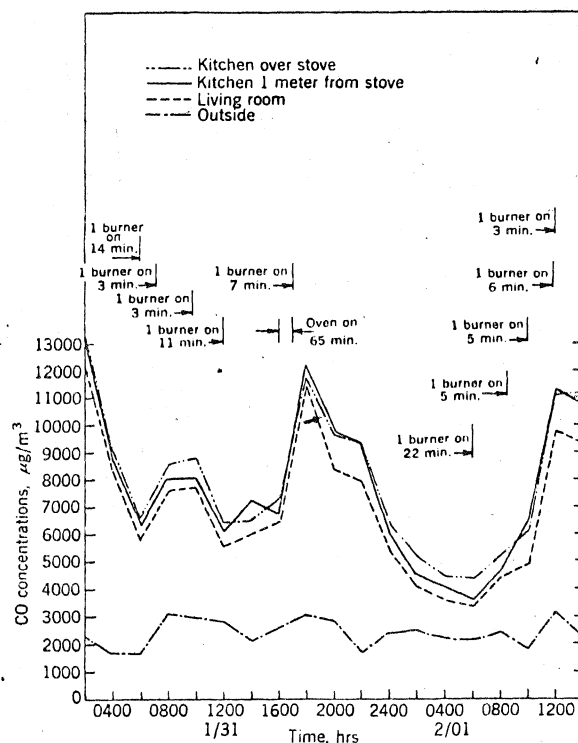


Figure 7. House No. 4: A time history of CO concentrations, 2 hr averages, winter 1974.

Mr. Wade is Associate Project Engineer, Mr. Cote is Senior Project Engineer, and Mr. Yocom is Chief Engineer at TRC—The Research Corporation of New England, 125 Silas Deane Highway, Wethersfield, CT 06109. This is a revised version of Paper No. 74-50 which was presented at the 67th Annual Meeting of APCA at Denver in June 1974.