

Lawrence Berkeley National Laboratory

Recent Work

Title

COMBUSTION-GENERATED INDOOR AIR POLLUTION. I. FIELD MEASUREMENTS 8/75 - 10/75

Permalink

<https://escholarship.org/uc/item/5cq454n8>

Author

Hollowell, Craig D.

Publication Date

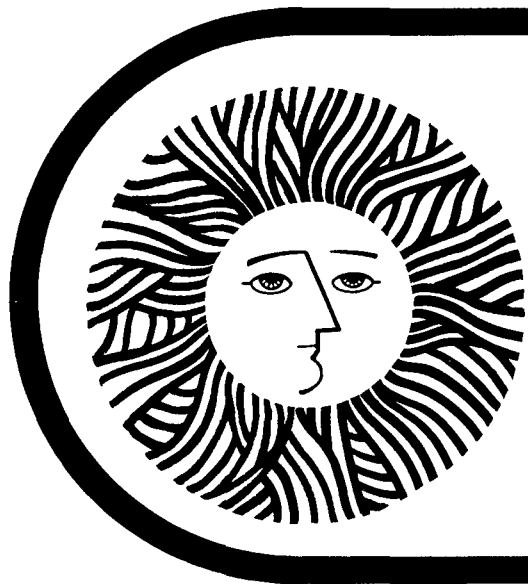
1976

00004405062

LBL-4416

c.1

RECEIVED
BERKELEY LABORATORY
FEB 24 1976
LIBRARY AND
DOCUMENTS SECTION



**COMBUSTION-GENERATED
INDOOR AIR POLLUTION**

I. FIELD MEASUREMENTS
8/75 - 10/75

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California

For Reference

Not to be taken from this room

LBL-4416
c.1

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

0 0 0 0 4 4 0 5 0 6 3

LBL-4416
UC-11
TID-4500-R63

COMBUSTION-GENERATED INDOOR AIR POLLUTION

I. FIELD MEASUREMENTS 8/75 - 10/75

Craig D. Hollowell, Robert J. Budnitz,
George D. Case, and Gregory W. Traynor

January 1976

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

LBL-4416

U O O O 4 4 0 5 0 6 4

COMBUSTION-GENERATED INDOOR AIR POLLUTION

I. FIELD MEASUREMENTS 8/75 - 10/75

Craig D. Hollowell, Robert J. Budnitz,
George D. Case, and Gregory W. Traynor

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

The indoor air quality of six homes with gas and electric cooking and gas heating appliances was characterized to determine the level of gaseous and aerosol air pollutants from typical indoor combustion sources. Field measurements of SO_2 , NO/NO_2 , O_3 , and CO were determined on a continuous basis. Total aerosol samples were collected on filter media for laboratory analysis by X-ray fluorescence and ESCA techniques for the determination of aerosol elemental composition and ionic species such as SO_4^- , NO_3^- , and NH_4^+ . Results of the study indicate that levels of gaseous and respirable aerosol air pollutants in the indoor environment do frequently exceed those levels commonly found in the outdoor urban air. Such findings may have a large impact on the future design of epidemiological studies, on energy conservation strategies for buildings, and on the need for more stringent control of air pollution from indoor combustion sources.

INTRODUCTION

Air pollution research has focussed almost exclusively on pollution in outdoor air and has virtually neglected the indoor environment despite the fact that the major proportion of the population spends far more time indoors than outdoors. Recent evidence (Refs. 1-8), however, indicates that levels of pollutants in the indoor environment can frequently exceed those levels which commonly occur in outdoor air. The importance of indoor air pollution, only now being recognized, will ultimately have a large impact on the future design of epidemiological studies, on energy conservation strategies for buildings, and on the need for more stringent control of air pollution from indoor sources.

A major problem in assessing adverse effects of air pollution on human health is the insufficient information on the magnitude and frequency of exposure to air pollution by the human subjects under study. The exposure data are deficient due to incomplete air pollution characterization of the various indoor and outdoor environments encountered by the human subjects and due to the difficulty of developing mathematical models that provide accurate estimates of human exposure by considering wide variations in spatial and temporal human activity.

Energy conservation measures call for sealing up buildings more tightly and this may have a detrimental effect on indoor air quality. If indoor air is significantly polluted from indoor sources, then the need for exchange with outside air is in conflict with those energy conservation measures which would restrict this exchange. The alternative to sealed buildings may be an effective heat exchange system where potential indoor air pollution could be mitigated by normal infiltration. The relationship between energy conservation measures for buildings and indoor air quality is not understood and needs to be investigated.

The need for better air pollution characterization requires a thorough understanding of indoor as well as outdoor air quality.

As mentioned, most people spend a majority of their time indoors, yet the air pollution characterization of the indoor environment is not well understood. Limited information suggests that the indoor environment has a vastly different mix, concentration and temporal distribution of gaseous and particulate air pollutants relative to the outdoor environment. It is thus essential that air pollution characterization of the indoor environment be undertaken in order to assess correctly the human exposures in epidemiological studies and the impact of energy conservation strategies on indoor air quality.

Most studies of indoor air pollution have been concerned with SO_2 , CO and/or total suspended particulate matter, and have assumed that the indoor levels arise from and are directly related to the outdoor levels (Refs. 1,2). Surprisingly little work has been done with respect to other potentially important indoor air pollution species, such as NO, NO_2 , nitrates, sulfates, metals, organics, and the respirable fraction of the particulate matter. Even more surprisingly, indoor generated air pollution has been neglected in most indoor air pollution studies until quite recently.

A number of indoor sources may contribute appreciably to the total indoor air pollution, notably those associated with combustion (i.e., cooking, heating, and smoking), with aerosol spray can usage, with cleaning, and with food preparation. To date, there are a handful of documented studies which suggest that indoor sources may give rise to levels of pollutants in indoor air which greatly exceed typical levels in the outdoor environment. Among these instances are the airborne build-up of carbon monoxide and suspended particulate matter from cigarette smoking (Ref. 3), nitric oxide and nitrogen dioxide from gas stoves (Refs. 4, 5, 6, 7), formaldehyde from construction materials (Ref. 8), vinyl chloride (Ref. 9) and fluorocarbons (Refs. 10, 11) from the use of aerosol devices containing these substances as propellants, and mercury from interior wall paint and unidentified sources (Refs. 12, 13).

These examples suggest that there may be additional types and sources of air pollutants, for example, those associated with combustion sources such as cooking and heating appliances. Although elevated

levels of NO and NO₂ have been observed during gas stove operation, the emissions from other combustion sources such as heating systems, water heaters, and clothes dryers have not been thoroughly investigated. More important is the fact that many nitrogen compounds, particulate as well as gaseous, were not considered in the gas stove studies, despite the recent demonstration that NO, NO₂, and NH₃ can rapidly undergo catalytic oxidation or reduction to other important air pollution species such as nitrates, nitric acid, ammonium, and organic nitrogen compounds of the amino- and pyridino-type (Ref. 14).

Because of recent recognition that indoor air quality deserves much more attention than it has thus far received, and because a number of energy-conservation measures that could affect indoor air quality might soon be implemented on a large scale, the Lawrence Berkeley Laboratory has initiated an indoor air pollution research study. The broad goals of this project are to characterize indoor air pollution; to identify the important sources, abundance, and fate of indoor air pollutants; to study the abatement of indoor pollution; to characterize exposures of the occupants to the important air pollutants; to study the health and welfare effects; and to assess the impact of various energy-conservation strategies on indoor air quality and human exposures to indoor air pollution.

Indoor air quality is a complex function of a number of variables which include outdoor levels of air pollution, indoor generation of pollutants, meteorology, permeability of the building, and type of operation of ventilation and/or air conditioning system. The initial phase of this study focuses on the characterization of air pollutants generated from indoor combustion sources. The work reported here is the field program undertaken in the summer and fall of 1975 to characterize gaseous and particulate air pollutants in six occupied homes with varying gas and electric cooking and heating configurations.

Further work during this phase of the study will expand the field characterization work to more indoor sites of varying composition and will focus on laboratory controlled experiments to study the emissions and control techniques of air pollutants from typical indoor combustion appliances.

EXPERIMENTAL PROGRAM

The principal objective of the field study described here was to obtain quantitative data on the relationship of indoor to outdoor air pollutant concentrations as a function of gas cooking and heating appliance use. Six homes in Berkeley and Albany, California were selected for this study. All homes were fitted with gas heating systems, five with gas stoves, and one with an electric stove. Field measurements reported here were made under conditions simulating typical cooking and heating usage. Only the home with the electric stove was characterized during a cool season when the heating system is normally operated, and is therefore the only home to be evaluated for the effect of gas heating systems on indoor air pollutant levels. Future field work will characterize additional homes to study the effect of heating systems in more detail. The major air pollutants that have been identified with gas combustion sources are carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO₂), and to a lesser degree, sulfur dioxide (SO₂) and particulates. The program also included measurement of ozone (O₃) which is not considered to be an indoor generated pollutant but which may penetrate into the indoor environment and react with the combustion generated pollutants, building materials, or other indoor sinks. Particulate samples were collected on 47 mm filters for laboratory chemical analysis by X-ray fluorescence (XRF) (Refs. 15,16) and electron spectroscopy for chemical analysis (ESCA) (Refs. 17,18,14) techniques. The components of the measurement system are given in Table 1. The instruments were located near the indoor and outdoor sampling locations and measurements were taken sequentially at both locations. The sample intake for the gas and electric stove measurements was placed in the breathing zone approximately 1.5 meters above the floor near the front of the stove. Measurements to study the effect of the heating system were made with the sample intake in the bedroom approximately 1 meter above the floor. Gases were sampled through 4 to 8 meters of 6.4 mm I.D. TFE teflon tubing at a rate of approximately 6 liters per minute (lpm)

Table 1. Indoor Air Pollution Measurement System

Parameters Measured and Instrumentation

Parameter Measured	Principle of Measurement	Manufacturer/Model
<u>Gases</u>		
SO ₂	UV Fluorescence	Thermo Electron 43
NO/NO ₂ /NO _x	Chemiluminescence	Thermo Electron 14D
O ₃	UV Absorption	Dasibi 1003-AAS
CO	Non-dispersive Infrared Absorption	Beckman 7000
<u>Aerosols</u>		
Total aerosol filter sampling equipment for laboratory chemical composition analysis by XRF and ESCA techniques	Pump with 47 mm filter holder	4 LBL Systems using Millipore cellulose 1.2 μm pore filters for XRF samples and Selas Flotronics silver 5.0 μm pore filters for ESCA samples

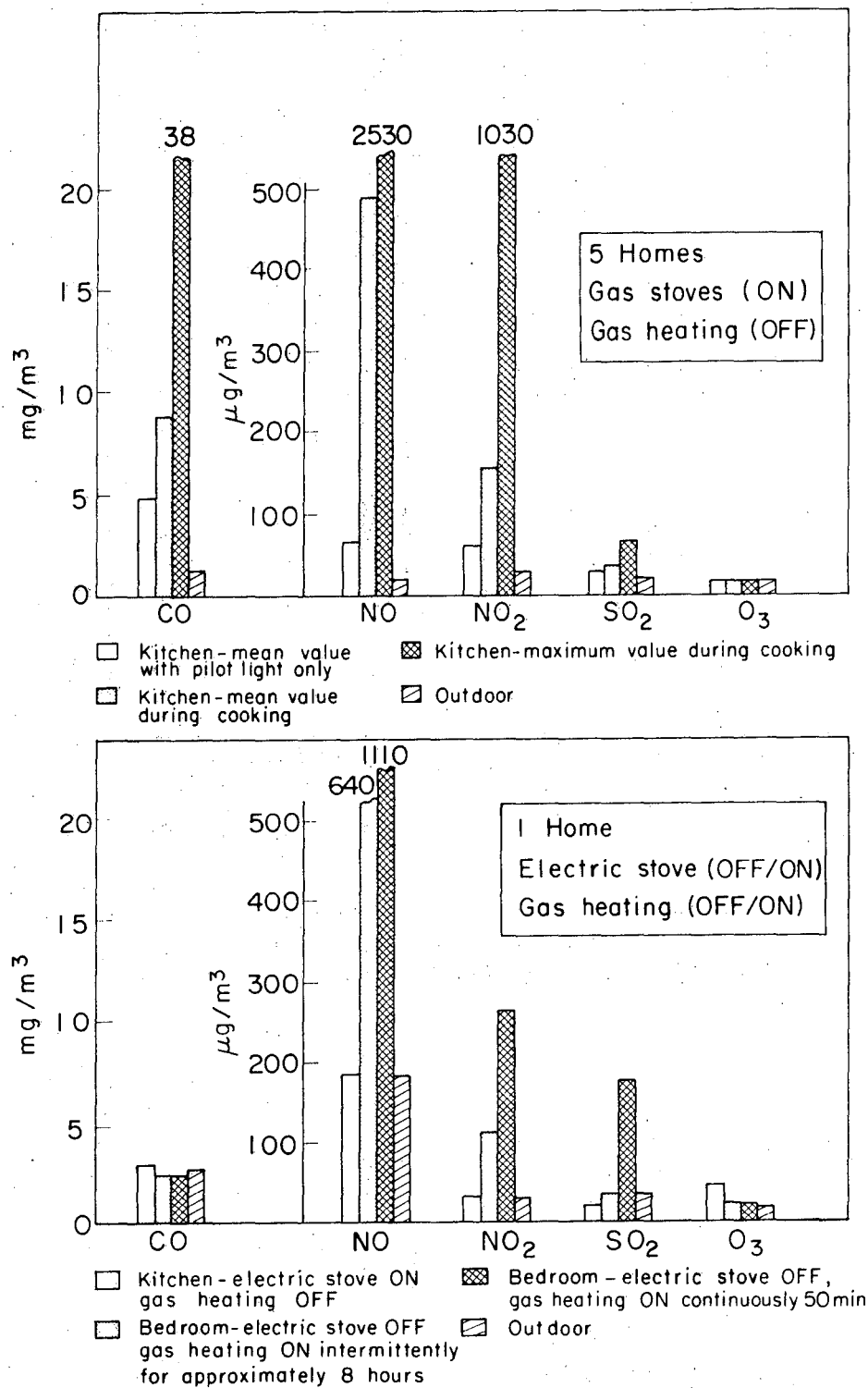
and measured on a continuous basis. This is equivalent to a retention time in the tubing of 2 to 4 seconds, which is sufficiently short to minimize wall losses and reactivity of the gases. Indoor and outdoor particulate samples were collected on 47 mm filters at a flow rate of approximately 70 lpm. The sampling periods ranged from 30 minutes for aerosols collected on cellulose filter media for XRF analysis to 2 hours for aerosols collected on silver filter media for ESCA measurements.

RESULTS AND DISCUSSION

Figure 1 summarizes the average indoor/outdoor data for gaseous air pollutant levels in the six homes under typical occupancy conditions of cooking and heating. The results clearly indicate high levels of CO, NO, and NO₂ and elevated levels of SO₂ from gas stoves, even during non-cooking periods when pilot lights are probably the only major indoor source of these gases. The results are consistent with other studies (Refs. 4,5,6,7) and report for the first time elevated indoor SO₂ levels associated with gas stoves. A small increase in O₃ was observed during usage of the electric stove, but no elevated levels of the other gases were seen. Figure 1 also shows the high levels of NO and NO₂ observed in the one home where the effect of a forced-air gas-fired furnace system was studied. The other five homes were not tested for the effect of gas heaters because the study was conducted in the warm summer months when the heaters are normally off. This study represents the first evaluation of the effects of heating systems on indoor air pollution levels. Previous studies (Refs. 19-24) have examined oil- and gas-fired residential and commercial heating systems; however, measurements were made of the flue gases to evaluate the contribution of heating systems to ambient outdoor air pollution and did not examine their effect on indoor air quality.

More detailed analyses of gaseous pollutant emissions from gas stoves were made in quasi-controlled experiments in some of the homes. Table 2 summarizes the data on the effect of cooking utensil construction material on gaseous emissions. Pans constructed of various materials (stainless steel with stainless steel, copper, and aluminum bottoms, iron, Pyrex, and Corning Ware Pyroceram) were used over one top gas burner to heat water. No appreciable differences in gaseous emissions were observed among the six pans tested.

The results on the effect of burner conditions are given in Table 3. Measurements were made about 60 cm above one top burner without modification of the flame, but under conditions of (1) without the



XBL7510-8561

Figure 1. Gaseous indoor and outdoor air pollutant levels observed at homes with varying cooking and heating configurations.

Table 2. Effect of Cooking Utensil Construction Material on Gaseous Emissions*
(Observed Values $\pm 15\%$)

	Background		Stainless Steel			Cast Iron Skillet	Pyrex	Corning Ware Pyroceram
	Outside	Inside	Stainless Steel Bottom	Copper Bottom	Aluminum Bottom			
CO (mg/m ³)	<1	9	27	32	29	34	25	25
NO ($\mu\text{g}/\text{m}^3$)	<15	85	740	585	565	715	665	590
NO ₂ ($\mu\text{g}/\text{m}^3$)	20	85	370	340	340	375	375	340
SO ₂ ($\mu\text{g}/\text{m}^3$)	<15	40	80	90	90	90	90	90

* Measurements in home No. 2 approximately 60 cm above the stove with one top gas burner on.

Table 3. Effect of Gas Burner Conditions on Gaseous Emissions*
(Observed Levels $\pm 15\%$)

Home Identification Number	Pollutant	Kitchen Background	One Burner On No Grate	One Burner On With Grate	One Burner On With Grate and All Stainless Steel Pan
2	CO (mg/m ³)	9	10	9	27
	NO ($\mu\text{g}/\text{m}^3$)	85	1050	1110	740
	NO ₂ ($\mu\text{g}/\text{m}^3$)	85	380	380	370
	SO ₂ ($\mu\text{g}/\text{m}^3$)	40	65	90	80
3	CO (mg/m ³)	1	2	3	13
	NO ($\mu\text{g}/\text{m}^3$)	25	165	125	160
	NO ₂ ($\mu\text{g}/\text{m}^3$)	30	115	65	125
	SO ₂ ($\mu\text{g}/\text{m}^3$)	<15	25	<15	<15
4	CO (mg/m ³)	3	4	3	3
	NO ($\mu\text{g}/\text{m}^3$)	55	1110	1230	680
	NO ₂ ($\mu\text{g}/\text{m}^3$)	60	450	470	380
	SO ₂ ($\mu\text{g}/\text{m}^3$)	<15	40	35	25
5	CO (mg/m ³)	4	8	9	8
	NO ($\mu\text{g}/\text{m}^3$)	75	1260	990	640
	NO ₂ ($\mu\text{g}/\text{m}^3$)	60	340	320	265
	SO ₂ ($\mu\text{g}/\text{m}^3$)	25	50	30	25

*Measurements in kitchen approximately 60 cm above the stove

grate, (2) with the grate, and (3) with the grate and stainless steel pan with water. The most obvious result is the high variability of gaseous pollutant emissions among the four stoves studied. CO emissions increased appreciably with two of the four stoves studied when the pan was placed on the burner; the NO emissions were reduced by 50% from the same stoves when the pan was placed above the flame. This presumably indicates a reduction in oxygen availability and redistribution of flame energy with a resultant reduction in flame temperature. These conditions could give rise to increased CO production due to incomplete oxidation of CO to CO₂ and reduced NO production in accordance with the high temperature dependent Zeldovich mechanism:



These results will be studied in more detail. The NO₂ and SO₂ levels were not appreciably affected by the burner conditions.

One recent study reported on the control of NO_x from gas stoves (Ref. 25). The results of this study showed that only modest reductions in emissions could be achieved by modification of flame aerodynamics; however, use of wire meshes to redistribute energy within the flame made possible a large reduction of NO_x emissions.

One of the homes was equipped with a ventilation fan above the stove and no exhaust duct from the oven to the outdoor air; the other homes, however, were fitted with an oven exhaust duct, but no fan. The effect of gas oven usage was studied in three homes and the results are summarized in Table 4. It is obvious that gas oven usage under poor ventilation conditions can result in elevated levels of CO, NO, NO₂, and even SO₂.

The studies on gaseous pollutants clearly indicate elevated levels of CO, NO, and NO₂ from gas combustion appliances. The duration of these elevated levels may be under one hour for gas stove usage, but may be continuous for gas-fired heating system usage in cool seasons. The U.S. National Ambient Air Quality

Table 4. Gaseous Air Pollutant Levels Observed in Homes With Gas Ovens*

(Observed Levels $\pm 15\%$)

Home Identification Number	2		3		5	
	No Duct Fan Off	No Duct Fan On	Duct No Fan	Duct No Fan	Duct No Fan	Duct No Fan
CO (mg/m^3)	23	6	2		7	
NO ($\mu\text{g}/\text{m}^3$)	2000	1000	500		150	
NO ₂ ($\mu\text{g}/\text{m}^3$)	850	320	150		95	
SO ₂ ($\mu\text{g}/\text{m}^3$)	110	65	<25		<15	

* Measurements in center of kitchen, approximately 1.5 meters above the floor, with the gas oven at 550°F for approximately 20 minutes.

Standards (Ref. 26) for CO, NO, and NO₂ are given in Table 5. Japan has promulgated a short-term NO₂ standard of 0.02 ppm (40 µg/m³) for 24 hours (Ref. 27) and it has been recommended that the EPA promulgate a one-hour NO₂ standard in the range of 0.1 to 0.35 ppm (200 to 700 µg/m³) (Ref. 28). The levels of NO₂ observed in the six homes all greatly exceed the Japanese 24-hour standard and exceed the proposed one-hour U.S. standard. Certainly the high NO₂ levels observed in this study deem that more attention be directed to the potential health impact of indoor combustion sources.

Ambient standards for NO have not been promulgated; however, a concurrent LBL study (Ref. 29) on the biotransformation of NO in blood indicates that the elevated NO levels observed in this study may have an impact on human health similar to, and in addition to, that attributed to CO (Ref. 30). Observed carbon monoxide levels exceeded the one-hour standard in a few cases and may be of concern.

Particulate air samples were collected in the study homes and analyzed by X-ray fluorescence and ESCA techniques. Figure 2 gives the mean indoor and outdoor particulate concentrations for S, Pb, Zn, Fe, and Ca from eight indoor/outdoor sample pairs collected during cooking in five homes with gas stoves. The results indicate an increase in indoor particulate sulfur during cooking while the indoor particulate levels for other species are comparable to or lower than the outdoor levels. No elevated sulfur levels, gaseous or particulate, were found in the home with the electric stove on.

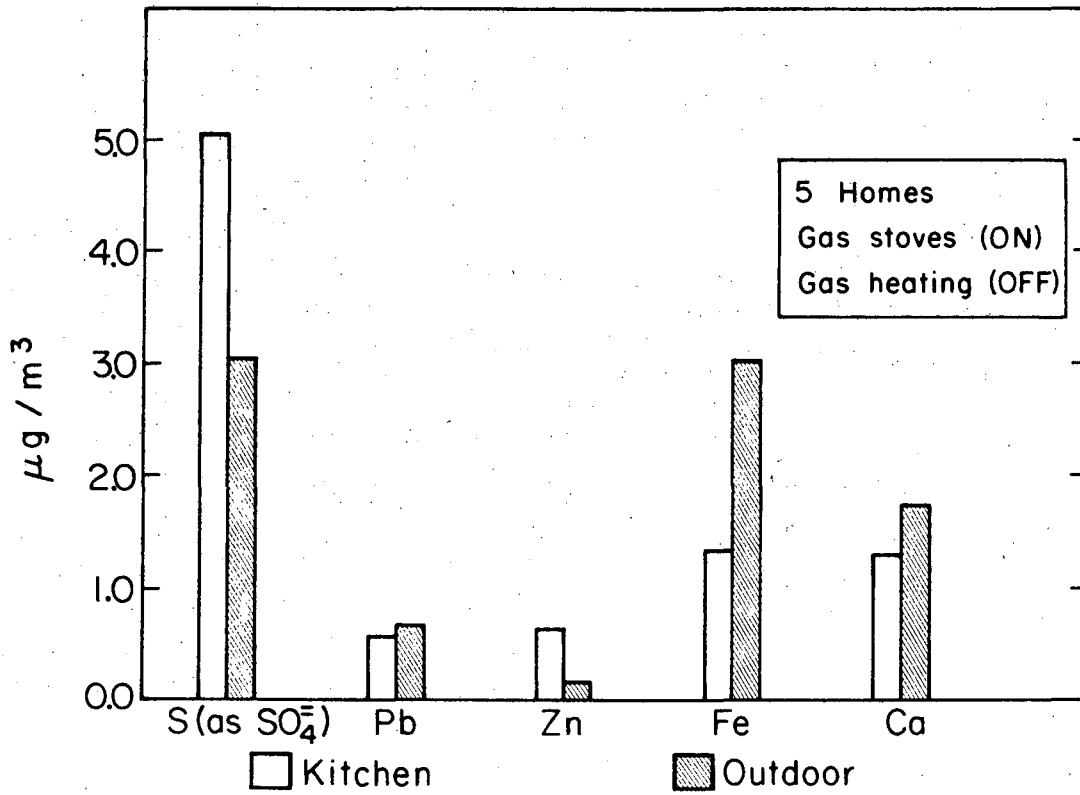
Sulfur and lead aerosols are typically found in California urban air in the particle size range of less than 2 µm; iron and calcium aerosols are typically greater than 2 µm in size; and zinc is found in all size ranges (Refs. 31, 32). The results shown in Figure 2 are consistent with recent studies (Refs. 33, 34) which show particulate loading to be lower indoors than outdoors as a result of less penetration of large particles from the outside air, but with higher indoor levels of respirable particles (<3.5 µm) due to indoor sources.

Figure 3 illustrates the elevated indoor particulate nitrogen levels observed in the home where the effect of the gas furnace was studied. The ESCA spectra illustrate the different nitrogen species

Table 5. National Primary Ambient Air Quality Standards*

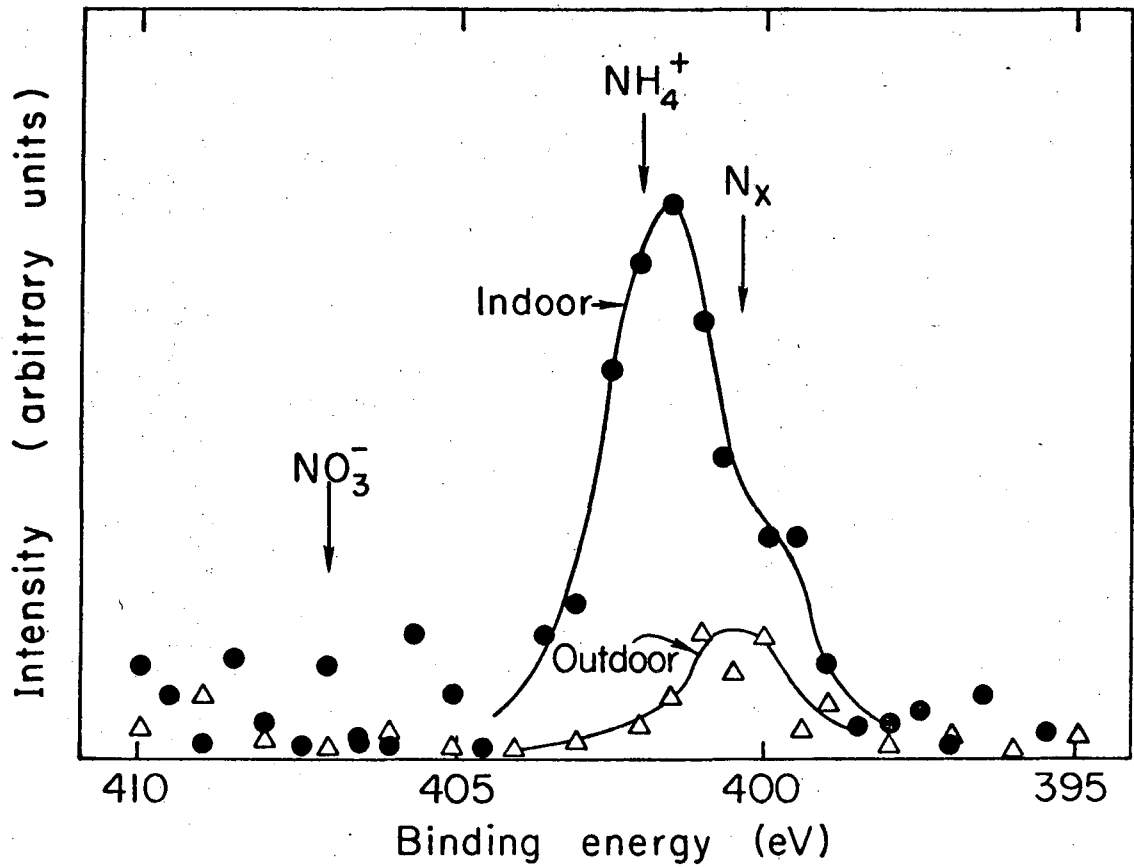
Pollutant	Averaging Time	Concentration
Carbon Monoxide	1 hr.	40 mg/m ³ (35 ppm)
	8 hr.	10 mg/m ³ (9 ppm)
Nitrogen Dioxide	Annual Arithmetic Mean	100 µg/m ³ (0.05 ppm)
Sulfur Dioxide	24 hr.	365 µg/m ³ (0.14 ppm)
	Annual Arithmetic Mean	80 µg/m ³ (0.03 ppm)

* National standards other than those based on annual arithmetic means or annual geometric means are not to be exceeded more than once per year.



XBL7510-8559

Figure 2. Indoor and outdoor particulate air pollutant levels observed at five homes with gas stoves during cooking. Levels indicated represent average of eight indoor/outdoor sample pairs collected on cellulose filters and analyzed by X-ray fluorescence analysis.



XBL7510-8560

Figure 3. Nitrogen (1s) photoelectron (ESCA) spectra of indoor and outdoor particulate samples taken at home with the gas furnace on. Individual peaks corresponding to NO_3^- , NH_4^+ , and N_x (organic nitrogen species) are indicated.

(NO_3^- , NH_4^+ , N_x [organic nitrogen]) observed indoors and outdoors; the peak areas are proportional to the relative atomic concentrations (as N) of these species. Most of the indoor nitrogen is found as NH_4^+ and N_x ; the outdoor nitrogen is found as N_x . In previous outdoor studies (Ref. 14), N_x was found to be either the dominant or at least major component of the total particulate nitrogen. The elevated levels of reduced nitrogen species should be particularly noted, because some of these (especially those labeled " N_x " in Figure 3, which are interpreted as NH_2 -type compounds) are species whose health implications deserve further study.

CONCLUSIONS AND FUTURE WORK

It is obvious from this study that elevated levels of gaseous air pollutants and particulate sulfur and nitrogen compounds are present in indoor environments with gas cooking and heating appliances. High levels of CO, NO, and NO₂ approach or exceed promulgated and proposed ambient air quality standards. Such findings may have a large impact on the future design of epidemiological studies, on energy conservation strategies for buildings, and on the need for more stringent control of air pollution from indoor combustion sources.

Future work at LBL will entail field and laboratory studies to characterize the air pollution from indoor combustion sources, namely gas/electric stoves, gas/oil heating systems, gas hot water heaters, gas clothes dryers and other appropriate combustion sources in homes, schools, and office buildings. The goals of this characterization study will be to examine in detail the sources, rates of emissions, and fates of gaseous and aerosol air pollutants. Laboratory studies will identify various parameters (e.g., flame temperature and geometry, venting conditions, air infiltration rate, etc.), which affect rates of emissions from cooking and heating combustion appliances and air pollution levels in the indoor environment. Field and laboratory measurements will be made with the LBL Mobile Atmospheric Research Laboratory capable of multi-point sampling, for such pollutants as SO₂, NO/NO₂, CO, O₃, aerosol size and aerosol chemistry. Measurements on field-collected aerosol samples will be performed by laboratory-based X-ray fluorescence, ESCA, combustion, and wet-chemistry techniques.

ACKNOWLEDGMENT

The authors especially thank J. M. Hollander for his encouragement of this work. Appreciation is expressed to R. D. Giaque for the X-ray fluorescence analysis and T. Novakov and R. Dod for the ESCA analysis of the aerosol samples. We thank D. A. Levaggi, W. Siu, and L. B. Potter of the Bay Area Air Pollution Control District for permission to use their Beckman 7000 carbon monoxide analyzer.

This work has been supported by the U.S. Energy Research and Development Administration.

REFERENCES

1. Benson, F.B., Henderson, John J., and Caldwell, D.E., "Indoor-Outdoor Air Pollution Relationships: A Literature Review," Publication No. AP-112, U.S. Environmental Protection Agency, Research Triangle Park, N.C. (1972).
2. Henderson, J.J., Benson, F.B., and Caldwell, D.E., "Indoor-Outdoor Air Pollution Relationships: Vol. II, An Annotated Bibliography," Publication No. AP-112b, U.S. Environmental Protection Agency, Research Triangle Park, N.C. (1973).
3. Penkala, S.J. and de Oliveira, G., "The Simultaneous Analysis of Carbon Monoxide and Suspended Particulate Matter Produced by Cigarette Smoking," Environ. Res. 9, 99 (1975).
4. Levy, A., Courant, R.W., Joseph, D.W., Merryman, E.L., and Spicer, C.W., "Evaluation of Measurement Methods for Indoor Levels of CO and NO_x," Battelle Columbus Laboratories, Columbus, OH 43201 (1974).
5. Lutz, G.A., Mitchell, R.E., Cote, R.W., and Keller, M.D., "Indoor Epidemiology Study," Battelle Columbus Laboratories, Columbus, OH 43201 (1974).
6. Wade, W.A. III, Cote, W.A., and Yocum, J.E., "A Study of Indoor Air Quality," J. Air Pollut. Contr. Ass. 25, 933 (1975).
7. Schwarzbach, E., "Zur Frage der Entstehung von Stickstoffoxiden bei Erdgasfeuerungen (The Question of the Formation of Nitrogen Oxides During Burning of Natural Gas)," Staub-Reinhaltung der Luft 35, 134 (1975).
8. Anderson, I., Lundqvist, G.R., and Mølhave, "Indoor Air Pollution Due to Chipboard Used as a Construction Material," Atmos. Environ. 9, 1121 (1975).
9. Gay, B.W., Jr., Lonneman, W.A., Bridbord, K. and Moran, J.B., "Measurements of Vinyl Chloride from Aerosol Sprays," in Annals of the New York Academy of Sciences, 246, 286 (1975).
10. Hester, N.E., Stephens, E.R., and Taylor, O.C., "Fluorocarbons in the Los Angeles Basin," J. Air Pollut. Contr. Ass. 24, 591 (1974).
11. Bridbord, K., Brubaker, P.E., Gay, B., Jr., and French, J.G., "Exposure to Halogenated Hydrocarbons in the Indoor Environment," Environmental Health Perspectives, 11, 215 (1975).
12. Foote, R.S., "Mercury Vapor Concentrations Inside Buildings," Science 177, 513 (1972).
13. Braman, R.S. and Johnson, D.L. "Selective Absorption Tubes and Emission Technique for Determination of Ambient Forms of Mercury in the Air," Environ. Sci. Technol. 8, 996 (1974).
14. Chang, S.G. and Novakov, T., "Formation of Pollution Particulate Nitrogen Compounds by NO-Soot and NH₃-Soot Gas-Particle Surface Reactions," Atmos. Environ. 9, 495 (1975).

15. Jaklevic, J.M., Goulding, F.S., Jarrett, B.V. and Meng, J.D., "Application of X-ray Fluorescence Techniques to Measure Elemental Composition of Particles in the Atmosphere," in Stevens, R.K. and Herget, W.F., Editors, Analytical Methods Applied to Air Pollution Measurements, Ann Arbor Science Publishers, Inc. (1974) pp. 123-146.
16. Giauque, R.D., Goda, L.Y. and Brown, N.E., "Characterization of Aerosols in California by X-ray Induced X-ray Fluorescence Analysis," Environ. Sci. Technol. 8, 436 (1974).
17. Hollander, J.M., Shirley, D.A., "Chemical Information from Photoelectron and Conversion Electron Spectroscopy," Annual Review of Nuclear Science, Segrè, E. (Editor), Vol: 20 (1970).
18. Novakov, T., Chang, S.G., and Harker, A.P., "Sulfates as Pollution Particulates: Catalytic Formation on Carbon (Soot) Particles," Science 186, 259 (1974).
19. Levy, A., Miller, S.E., Barrett, R.E., Schulz, E.J., Melvin, R.H., Axtman, W.H., and Locklin, D.W., "A Field Investigation of Emissions from Fuel Oil Combustion for Space Heating," American Petroleum Institute Publication 4099 (November 1, 1971).
20. Barrett, R. E., Miller, S. E., Locklin, D.W., "Field Investigation of Emissions from Combustion Equipment for Space Heating," Environmental Protection Agency, Publication EPA-R2-73-084a, and American Petroleum Institute Publication 4180 (June 1973).
21. Hall, R.E., Wasser, J.H., and Berkau, E.E., "A Study of Air Pollutant Emissions from Residential Heating Systems," Environmental Protection Agency Publication EPA-650/2-74-003, (January 1974).
22. Barrett, R.E., Locklin, D.W., and Miller, S.E., "Investigations of Particulate Emissions from Oil-Fired Residential Heating Units," Environmental Protection Agency Publication EPA-65-/2-74-026 (March 1974).
23. Michel, B., Neufelder, M., and Pruggmayer, D., "Emission of Pollutants by Domestic Fireplaces, Exhaust Gas Measurements on Oil and Gas Heaters," Staub Reinhaltung der Luft in English, 34, 129 (1974).
24. Lützke, K., "Emission en von Stickstoffoxiden aus Feuerungsanlagen: (Emissions of Nitrogen Oxide from Industrial and Domestic Combustion Installations) "Staub-Reinhaltung der Luft, 35, 127 (1975).
25. Mitchell, R.E., Taylor, B.R., Williams, G.C., and Sarofim, A.F., "Control of Nitric Oxide Emissions from Gas-Range Burners," Paper 75-09.3, presented at the 68th Annual Meeting of the Air Pollution Control Association, June 15-20, 1975, in Boston, Massachusetts.
26. Environmental Protection Agency, "National Primary and Secondary Air Quality Standards," Federal Register, 36, 8186 (April 20, 1971).

27. Ise, A., Materials Research and Process Development Department, Toyota Motor Co., Aichi, Japan, Private Communication (July 16, 1975).
28. U.S. Congress, Committee on Interstate and Foreign Commerce, Subcommittee on Health and the Environment, House of Representatives, "Clean Air Act Amendments — 1975, Hearings," (Washington, D.C., 1975).
29. Case, G.D., Schooley, J.C., and Dixon, J., "Uptake and Metabolism of Nitrogen Oxides in Blood," Report LBL-4417, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720, presented at the 20th Annual Biophysical Society Meeting Feb. 25, 1976 in Seattle, WA.
30. Snodderly, D.M., "Biomedical and Social Aspects of Air Pollution," Adv. Environ. Sci. Technol. 3, 157 (1974).
31. Hidy, G.M., "Summary of the California Aerosol Characterization Experiment," J. Air Pollut. Contr. Ass. 25, 1106 (1975).
32. Giaouque, R.D., Goda, L.Y., and Garrett, R.B., "X-ray Fluorescence Analysis of ACHEX Aerosols," Report LBL-4414, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720 (October 21, 1975).
33. Anderson, I., "Relationships Between Outdoor and Indoor Air Pollution," Atmos. Environ. 6, 275 (1972).
34. Lum, R.M., and Graedel, T.E., "Measurements and Models of Indoor Aerosol Size Spectra," Atmos. Environ. 7, 827 (1973).

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720