can be important and are not easily addressed in data analyses. These variables add an additional degree of uncertainty to a complex situation in determining the impact of gas appliances on indoor air quality.

References

(1) Baker, P. E.; Cunningham, S. J.; Becker, E. W.; Colome, S. D.; Wilson, A. L. An Overview of the Residential Indoor Air Quality Characterization Study of Nitrogen Dioxide. To be presented at Indoor Air '87 Conference, August 1987, Berlin, Germany.

(2) Colome, S. D.; Wilson, A. L.; Baker, P. E.; Cunningham, S. J.; Becker, E. W. Analysis of Factors Associated with Indoor Residential Nitrogen Dioxide: Multivariate Regression Results. To be presented at Indoor Air '87 Conference, August 1987, Berlin, Germany.

(3) Gas Engineers Handbook, First Edition. Industrial Press Inc., 1974, U.S. Library of Congress; Catalog Number 65-17328, pp.12/94-12/96.

(4) Girman, J. R.; Allen, J. R.; Lee, A. Y. A Passive Sampler for Water Vapor. Proceedings of the 3rd International Conference on Indoor Air Quality and Climate. 1984, 4, pp.227.

(5) Leaderer, B. P.; Schaap, L.; and Dietz, R. N. Evaluation of the Per Fluorocarbon Tracer Technique for Determining Infiltration Rates in Residences. Environmental Science and Technology, 1985, 19, pp.164.

(6) Palmes, E. D.; Gunnison, A. F.; Dimattio and Tomcayk. Personal Sampler for NO_2. American Industrial Hygiene Association Journal, 1976, 37, pp.570-577.

AN OVERVIEW OF THE RESIDENTIAL INDOOR AIR QUALITY CHARACTERIZATION STUDY OF NITROGEN DIOXIDE

Phillip E. Baker, Samuel J. Cunningham, and Edward W. Becker
Southern California Gas Company, Los Angeles, CA, U.S.A.

Steven D. Colome
University of California at Irvine, Irvine, CA, U.S.A.

A. L. Wilson
Wilson Environmental Associates, Sierra Madre, CA, U.S.A.

Abstract

The Southern California Gas Company Characterization Study evaluates factors that influence residential indoor nitrogen dioxide concentrations in a temperate geographical region with natural gas appliances and housing construction consistent with a mild climate. Residential homes in the Los Angeles basin were identified by stratified cluster sampling. Approximately six hundred homes were recruited to participate in the study by telephone contact thru random digit dialing. Passive dosimetry measurements included one-week sampling for nitrogen dioxide, air exchange rates, and absolute humidity. Measurements were taken in the kitchen, master bedroom and outside during the spring, summer and winter seasons.

Introduction

Governmental agencies, as well as organizations associated with the academic community, have been raising concerns since the mid-1970's regarding the quality of indoor air. Since a majority of people spend most of their time within the increasingly energy-efficient confines of a variety of building structures, it becomes ever more important to examine indoor levels of pollutants, such as radon gas, cleaning solvents, asbestos, formaldehyde, and combustion products (5).

Outdoor levels of NO_2 have been monitored for years. In the United States, Governmental standards have been developed, and they continue to be reviewed, debated and modified. The Southern California Gas Company (SoCalGas) operates in a territory which includes an area with one of the highest outdoor levels of NO_2. The Los Angeles basin is listed as a "non-attainment" area for NO_2 by the United States Environmental Protection Agency. Outdoor levels consistently exceed the Federal standard dictated by law.

Previous indoor air quality research, conducted mostly in colder climates in areas with lower ambient levels of NO_2, suggested that the use of natural gas appliances, together with energy-saving techniques that reduce air infiltration into the home could cause indoor levels of NO_2 to exceed the outdoor concentrations (4). Due to such concerns, SoCalGas initiated a residential indoor air quality Characterization Study of nitrogen dioxide in 1984, which ran until the early months of 1985.

Methodology

Over six hundred homes were randomly selected from chosen locations within Southern California to represent typical residences in different geographical and climatological regions of the SoCalGas service area. Participants were recruited in the beach communities, the Los Angeles Basin, Inland Orange County, and desert communities. Selection criteria were not based upon gas appliance type, age of home, income, or any parameter other than the occupant stating that he/she intended to remain in the home for at least two years. The selection of participants from all homes in the chosen communities provided a sample of various housing types and gas appliances typical of Southern California.

One-week tests were conducted in the spring, summer, and winter in each home. Nitrogen dioxide, air exchange rates and humidity measurements were taken in the kitchen, master bedroom and outside of each home. The chosen measurement technique used passive diffusion tube samples. Data were also gathered regarding appliances, housing characteristics, and lifestyle patterns during each of the three test periods.

Prior to the March and July tests, part-time technicians visited each home and installed the samplers. After the March test, and again after the July test, the participants mailed the exposed tubes back for analysis. Prior to the January test, specially trained SoCalGas Customer Services Representatives visited each home to install the samplers and to record certain data concerning gas appliances. After the January test, the same Representatives returned and gathered all sampling tubes and associated materials.

After the laboratory analyses were complete, the measured parameters were then correlated with appliance types and other recorded information to characterize Southern California indoor NO_2 concentrations (2).

Data Analysis

A primary objective of the study was to determine the relative importance of gas combustion appliances to the level of residential indoor NO_2, and to identify appliances that may contribute to elevated concentrations. In order to test the importance of residential gas combustion appliances on the indoor levels, data from the full sample of homes was used. This was done by multiple linear regression analysis with the SPSS statistical software package (6). The analyses focused on levels of NO_2 in the bedroom during January. The bedroom measurement was selected since it was located away from the immediate influence of cooking appliances and, therefore, increased the likelihood of detecting effects from other combustion appliances. The January test period was selected because furnace systems were in use. The homes also tended to be kept at their tightest with closed windows and doors, thus, reducing the air exchange and minimizing effects from outdoor sources.

Results

The data collected provided some unexpected results and led to a greater understanding of the complexities of indoor NO_2 in Southern California. Table 1 indicates values typical of the Los Angeles basin.

Table 1: One-week Average NO_2 as Measured with Palmes Tubes (ug/m^3)

Test Period	Percentile	Location		
		Kitchen	Bedroom	Outside
Spring (N = 597)	90th	146	97	80
	Median	73	48	52
	10th	26	21	28
Summer (N = 444)	90th	153	114	120
	Median	89	69	78
	10th	38	31	32
Winter (N = 405)	90th	213	138	164
	Median	101	70	106
	10th	44	31	64

Outside NO_2 levels significantly influence the inside concentrations, and on average, contribute more NO_2 indoors than does the average gas appliance. Gas ranges with standing gas pilots were also found to be associated with higher indoor NO_2 levels than gas ranges with electronic ignitions. The most unexpected finding was that some vented appliance types were associated with elevated NO_2. At least 20% of the wall and floor furnaces (3) sampled are suspected to have significantly contributed to the measured indoor NO_2 values. Ruptured fireboxes and poor venting are the probable causes for those higher concentrations of indoor NO_2.

Homes with a wall furnace recorded wintertime average NO_2 values 26 to 41 ug/m^3 higher than homes with a forced air furnace when both contained gas ranges. Homes with floor furnaces had wintertime average NO_2 concentrations 44 to 61 ug/m^3 higher than homes with a forced air furnace when both contained a gas range.

Homes with gas ranges and pilots had a 17 to 46 ug/m^3 higher average NO_2 concentration during the winter than homes with electric ranges. Compared to homes with electric ranges, pilotless gas ranges had an average of 17 ug/m^3 higher NO_2 concentration in the kitchen. No significant difference was found in the bedroom, however, between homes with electric ranges and those with pilotless gas ranges. Homes with gas ranges also had, on average, higher NO_2 levels during the spring and summer. The greatest difference between homes with a gas vs. electric range was observed in the kitchen.

The analyses supporting these results were not intended to identify factors associated with the highest indoor NO_2 concentrations. Rather, these analyses indicate average contributions from appliance types. Segregation of homes with the highest measured NO_2 has identified characteristics associated with these high levels (1).

Another unexpected finding was that reducing the air infiltration into the home would not necessarily increase the indoor NO_2 for the typical home with gas appliances. This is due to the high outside NO_2 concentrations in the study area. The findings suggest that for most Southern California homes, energy conservation measures that reduce air infiltration may actually reduce indoor NO_2 levels.

Conclusions

The following are major findings and conclusions. All statements refer to the one-week average NO_2 concentrations as measured with Palmes diffusion tubes.

- On average, outside NO_2 sources are the largest contributor to indoor NO_2 concentrations in the Los Angeles basin. Certain gas appliances are also strongly related to increased indoor NO_2 concentrations.
- Poorly maintained and malfunctioning gas appliances, illegal unvented space heaters, and the improper use of the range/oven to heat the home were found to be the most probable cause for the highest indoor NO_2 concentrations.
- From all the homes participating in the study, the following sources were identified as contributors to indoor NO_2. They are listed in order of relative contribution (most to least):
  - Outside NO_2 concentrations
  - Floor furnaces
  - Gas range/ovens with standing pilots
  - Gas range/ovens with electronic ignitions
  - Wall furnaces
- Gas-fired forced air furnaces were not found to contribute to indoor NO_2 concentrations.
- Homes containing gas range/ovens with electronic ignitions had significantly lower indoor NO_2 than homes with piloted gas range/ovens.
- On average, homes in the Los Angeles basin area with lower air exchange rates (weatherized or energy-efficient) are more likely to be associated with lower NO_2 than homes with higher air exchange rates.
- Average indoor NO_2 is inversely proportional to home size.

- Older homes are associated with higher NO_2, and newer homes are associated with lower NO_2 levels.
- Indoor NO_2, measured in the bedroom area is, on average, lower than outside NO_2; and indoor kitchen NO_2 is, on average, greater than outside NO_2.
- One week average indoor NO_2 is proportional to outside NO_2.
- Indoor NO_2 appears to vary seasonally with the highest indoor NO_2 concentrations reported in the winter for most homes and appliance types.
- The amount of gas used in the winter test was not found to have a significant correlation with indoor NO_2.
- General trends of new residential structures that include energy conservation measures, and the installation of gas ranges with electronic ignition and forced air furnaces favor, on average, a decrease in the level of indoor NO_2 concentrations in the Los Angeles basin.

References

(1) Baker, P. E.; Cunningham, S. J.; Becker, E. W.; Colome, S. D.; Wilson, A. L. Evaluation of Housing and Appliances Characteristics Associated with Elevated Indoor Levels of Nitrogen Dioxide. To be presented at Indoor Air '87 Conference, August 1987, Berlin, Germany.

(2) Colome, S. D.; Wilson, A. L.; Baker, P. E.; Cunningham, S. J.; Becker, E. W. Analysis of Factors Associated with Indoor Residential Nitrogen Dioxide: Multivariate Regression Results. To be presented at Indoor Air '87 Conference, August 1987, Berlin, Germany.

(3) Gas Engineers Handbook, First Edition. Industrial Press Inc., 1974, U.S. Library of Congress, Catalog Number 65-17328, pp.12/94-12/96.

(4) Spengler, J. D.; Duffy, C. P.; Letz, R.; Tibbits, T. W.; and Ferris, B. G. Nitrogen Dioxide Inside and Outside 137 Homes and Implications for Ambient Air Quality Standards and Health Effects Research. Environmental Science and Technology, 1983, 17, pp.164.

(5) Spengler, J. D. and Sexton, K. Indoor Air Pollution. A Public Health Perspective. Science, 1983, 221, pp.9-12.

(6) SPSSx Users Guide, 2nd Edition, New York: McGraw-Hill, 1986