calculated time
groups in the

***	P
15	<0.001
24	<0.001
11	<0.002
15	<0.001

(μg/m³)
(μg/m³)
ated NO_2 exposure
(μg/m³)

rsonal NO_2
n that

R^2 (%)	P
91	<0.001
93	<0.001

1550

MULTIVARIATE MODEL FOR PREDICTING NO_2 LEVELS IN RESIDENCES BASED UPON SOURCES AND SOURCE USE

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Abstract

Diffusion-type passive monitors were placed for a two-week period in each of 303 residences in the New Haven (Conn.) area during a 12 week sampling period (January to April 1983. For each home NO_2 levels were recorded outdoors, and in three rooms. Data were obtained on NO_2 sources, the level of use of these sources, and on building characteristics from an initial questionnaire, a bi-weekly telephone interview, daily diaries and from tax assessor records. Multivariate analysis of the data indicates that over 65% of the variation in indoor NO_2 concentration can be accounted for by variations in outdoor NO_2, the use and type of kerosene heaters, and the level of use of gas appliances. The major portion of the unexplained variation is probably due to variations in infiltration rates, sink terms and the accuracy to which independent terms were reported.

Introduction

In order to assess the health risks associated with exposure to air contaminants it is necessary to determine the total exposure to those air contaminants. Such exposures occur in different places, and because of the relatively large fraction of time people spend in indoor non-occupational environments (5) these environments must be especially considered. Indoor environments also are characterized by their potential for high concentrations of several important contaminants (2). The level of a contaminant in indoor spaces is governed by the complex interaction of the number of variables, which include the type, number and the characteristics of indoor sources, building characteristics such as infiltration, ventilation and sink terms, and the behavior of the occupants of a space.

As part of a field study of indoor pollutants conducted in the general area of New Haven, Conn., we undertook a monitoring program to assess air pollutant levels in residences, and to evaluate the factors which affect those concentrations. Emphasis was placed on NO_2 because of its potential health importance as an indoor air contaminant (2). The extensive measurement data collected can be used for the development of a predictive model which allows the estimation of concentrations in residences in which no direct measurements were made, on the basis of interview and other data which describe the presence and the use patterns of sources, and which describe the characteristics of the building containing the space.

Methods

The monitoring program assessed air pollutant levels in residences with kerosene space heaters and systematically selected neighboring residences without such heaters. An initial questionnaire was administered to all participants to obtain baseline information on the number and type of indoor sources of air contaminants (e.g. kerosene heaters, gas cooking stoves, tobacco combustion), source use, the physical attributes of the residences (insulation, storm windows, etc.) and heating system characteristics of the residences (type of central heat, temperature settings, etc.). Town tax assessor's records were used to supplement and verify building characteristics reported in the initial questionnaire. Source use data were also obtained from a bi-weekly telephone questionnaire administered to all participants and corresponding with the air sampling periods.

Integrated two-week average NO_2 concentrations were measured using passive diffusion samplers (4) in 303 residences, each over one two-week period between January 8 and April 3, 1983. Eighteen of these homes were sampled twice in non-consecutive periods. Two-week average NO_2 levels were obtained outdoors and for three separate locations in each residence (kitchen, living room and bedroom). The passive monitoring data were supplemented by the continuous monitoring of gases (O_2, CO_2, CO, NO, NO_2 and SO_2) in two locations indoors (living room and bedroom) and outdoors for 14 residences (1).

Multiple linear regression was used to find the best model to predict NO_2 values. The dependent variables considered individually in this analysis were NO_2 levels in the kitchen, family room and bedroom of the residences. The independent variables considered were outdoor NO_2 levels, the number of unvented kerosene space heater, hours of use for each heater, the type of kerosene space heater (convective or radiant), the manufacturer's BTU/hr rating, the presence of a gas cooking stove and/or oven, minutes of gas burner use, minutes of gas oven use, the use of a venting fan during cooking, the presence of other gas appliances, the presence of tobacco smokers, the volume of the residence, the volume of the kitchen, the volume of the living room (room with heater) and the period in which the NO_2 samples were taken. NO_2 concentrations and volumes were converted to log. Interactive terms for the independent variables (ie kerosene heater type x BTU rating) and total NO_2 emissions (the product of the emission rate, BTU rating and hours of heater use for each heater type) were also considered in the analysis.

The statistical procedures contained in the Statistical Analysis System (SAS, release 82.3) were used to develop the predictive models, one for each indoor location. The CP statistic, which gives an estimate of the standardized total mean square error for the fitted values, was used to select variables for the models. Models for which the CP value is less than or equal to the number of parameters tend to have little bias due to the exclusion of important predictors. The general strategy was to minimize the CP so that both the variance and the bias were reduced for the predicted values. A linear prediction model was then fitted to the selected variables for each room.

Results and Discussion

Three hundred-nineteen units of observation were used to develop the models. Of the residences sampled, 147 had no kerosene space heater or gas cooking stove; 96 had one heater but no stove; 42 had a stove but no heater; 18 had a heater and a stove; 13 had two heaters but no stove; and 3 had two heaters and a stove. Thirty residences had other gas appliances and 109 had at least one smoker. A descriptive analysis of the exposure assessment data base is presented elsewhere (3). The results of initial efforts to develop a NO_2 prediction model are presented here.

The NO_2 predictive models by location are presented in Table 1.

Table 1. Regression Analyses† for Predicting Log NO_2* Levels ($\mu g/m^3$) By Room Location

Parameters	Kitchen	Living Room	Bedroom
Intercept	1.491	1.416	1.374
	(0.223)	(0.216)	(0.239)
Coefficients			
Outdoor	0.230	0.250	0.229
NO_2(log)*	(0.084)	(0.082)	(0.091)
Heater use	0.090	0.093	0.099
(hrs/day)	(0.007)	(0.007)	(0.007)
Gas oven	0.117	0.100	0.130
(hrs/day)	(0.022)	(0.021)	(0.020)
Gas burners	0.427	0.206	-
(hrs/day)	(0.107)	(0.104)	
Convective	0.654	0.630	0.563
(1=present)	(0.083)	(0.081)	(0.080)
Radiant	0.294	0.242	-
(1=present)	(0.117)	(0.114)	
Other gas	0.320	0.268	0.330
(1=present)	(0.100)	(0.097)	(0.106)
R^2	0.656	0.641	0.600
Degrees of Freedom	7, 308	7, 308	5, 309
Root MSE	0.595	0.577	0.638

* Log NO_2 = log (NO_2 + 1)
† The standard error of the estimate is presented in parenthesis.

The result indicate that 65.6% of the variation in NO_2 concentrations in the kitchen 64.1% of the variation in living room NO_2 levels can be accounted for by variations in: outdoor NO_2 levels, type of heater, hours of heater use, hours of gas burner use, hours of gas oven use and presence of other gas appliances. Sixty percent of the variation in NO_2 concentrations in the bedroom can be accounted for by variations in outdoor NO_2 levels, use of a convective heater, hours of heater use, hours of gas oven use and presence of other gas appliances. Several observations from this analysis are notable:

1) The intercept, coefficient and standard error of the estimate for any given independent variable, are very similar across indoor locations. This indicates that there is reasonably rapid mixing taking place throughout the residence for most of the sources. The exception to this is gas burner use which decreases from 0.427 (0.107) in the kitchen to being essentially zero ($p>0.05$) in the bedroom model. This decrease in magnitude and significance indicates that the effect of the gas cooking stove decreases as distance from the source increases, possibly reflecting less than ideal mixing or the dominant impact of infiltration and sink terms.

2) The effect of a convective heater is more than double that of a radiant heater, reflecting the larger NO_2 production rate from the convective heater.

3) The radiant heater variable was not significant ($p>0.05$) in the bedroom, but it was significant in the kitchen and living room. This is probably a function of the lower NO_2 production rate of the radiant heaters, resulting in lower house NO_2 levels and dominance by other sources and sink terms.

4) The interaction term of kerosene heater type and BTU rating did not add to the explained portion of the variation and therefore was dropped from the analysis reducing the number of independent variables. This interaction term was not significant because the radiant and convective heaters fell into separate BTU categories with little overlap. Use of the total NO_2 emissions dependent variable in place of the hours of heater use, type of heater and BTU rating dropped the explained portion of the variation down to 55%. The reduction in explained variation in the model resulting from the use of the aggregated independent variable (total NO_2 emissions) shows that variations in the disaggragated independent variables (hours of use and heater type) is important in understanding the outcome. The inclusion in the models of the type of second kerosene heater was significant but only added an additional 1% to the explained variation while the number of hours of heater use for the second heater was not significant. There were too few observations of residences with second heaters that had appreciable use so they were dropped from the analysis.

5) The effect of smoking on indoor NO_2 levels was not seen in these analysis. This may be due to the relatively low contribution of smoking (3) in the face of higher NO_2 productng sources. This analysis is based upon the presence or absence of smoking. Further analysis on the number of cigarettes smoked in the home may elucidate the relationship. In the bedroom where NO_2 levels were lowest, the smoking variable showed a significance level of $p = 0.058$.

6) The volume of the kitchen and living room were not significantly related ($p>0.05$) to NO_2 levels in any location, although the total residence volume had a borderline effect ($p = 0.07$) in the bedroom. This indicates that there is rapid mixing of NO_2 throughout the residences and that infiltration and sink terms rather than volume dominate.

The unexplained variance in the models can be attributed primarily to the accuracy with which the independent variables were defined and to the variations in infiltration rates and sink terms. Data from the continuously monitored residences provide some insights into the importance and variability of the latter two factors. Figure 1 shows a comparison between calculated decay rates for the non-reactive gases, NO and CO_2 in the continuously monitored homes. The decay rates were calculated from the point at which the kerosene heater was shut off to the baseline concentration in the room and are indicative of the infiltration rate (air changes per hour) of the residence. There was no statistical difference ($p>0.05$) in the decays of NO and CO_2. Figure 1 shows that infiltration rates between homes can vary by a factor of 10 and within residences by more than 2. An accurate assessment of the infiltration rate would no doubt substantially improve the explained variation in NO_2 levels in the model.

Figure 2 shows the observed relationship between the decays (in ach) of non-reactive gas and NO_2 in the homes continuously monitored. The difference between the NO_2 decay rate and the non-reactive decay rate is an indication of the sink term for NO_2. While the decay of NO_2 is always greater than the non-reactive gases, no consistent pattern for non-reactive gases either within or between residences is evident. The removal of NO_2 by sinks is highly variable and therefore important in more accurately modeling levels of NO_2 in residences. The accurate characterization of the sink term and infiltration will greatly increase the explained variation in the models shown in Table 1.

Conclusion

A preliminary multivariate model is presented for predicting NO_2 levels in residences as a function NO_2 sources, source use and building characteristics. The model is based upon data gathered in an extensive field study of indoor air contaminants associated with unvented combustion sources; it explains over 65% of the variation in indoor NO_2 levels. Additional analysis is needed to further define the factors important to assessing indoor air pollutant levels.

Acknowledgements

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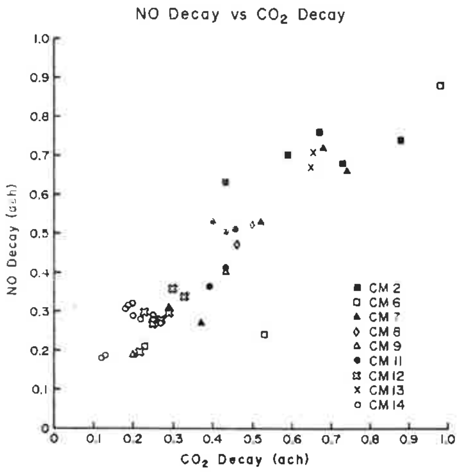

Fig. 1.

Comparison of NO and CO_2 decay rates calculated from gas decay measured in continuously monitored homes. CM refers to the number of the continuously monitored house. Each point represents a single decay event for the residence. Significant differences ($p < .05$) were not found between the NO and CO_2 decays.

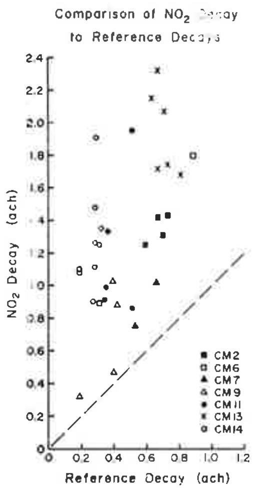

Fig. 2.

Comparison of the NO_2 and reference decay rates calculated from the decays measured in the continuously monitored homes. The reference decay rate was either NO or CO_2 and chosen on the basis of which one had the smallest confidence intervals associated with the calculated slope. Each point represents a single decay event for the residences. The 1 to 1 slope which would be expected if there were no NO_2 sink terms is also shown.

PERSONAL EXPOSURE:
INDOOR/OUTDOOR RELATIONSHIPS