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NITROGEN DIOXIDE LEVELS IN HOMES IN AVON, ENGLAND

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INTRODUCTION

ALSPAC and the BRE Indoor Environment Study

A survey of nitrogen dioxide (NO_2) levels in homes has been carried out by the Building Research Establishment (BRE) as part of the Bristol University "Avon Longitudinal Study of Pregnancy and Childhood (ALSPAC)"[1]. This paper describes the background, method and simple descriptive statistics to show what NO_2 concentrations were found. Bivariate and multivariate analysis were also carried out to identify associations between NO_2 concentrations and possible determinants (e.g. the presence of a gas cooker); all but the most basic of those results are given in a companion paper[2].

In ALSPAC, women are recruited in early pregnancy, and the health of the children will be monitored for seven years from birth. The county of Avon was considered suitable for the English study because it has a mixture of urban and rural areas, varied industry, and a population which is demographically representative of the rest of Britain. To be eligible for the study, subjects had to be resident in the study area while pregnant and have an expected date of delivery between 1 April 1991 and 31 December 1992. Approximately 14,000 women entered the English study.

BRE conducted the "ALSPAC Indoor Environment Study" which was a survey of air quality in 174 homes of participants in the main study. Approximately ten women were recruited each month from November 1990 until March 1992, from a list of volunteers supplied to BRE by Bristol University. Participants completed initial and post-natal questionnaires, and up to twelve monthly updates on their homes and activities. The initial questionnaires were completed in conjunction with the placing of samplers to detect levels of NO_2 and other pollutants inside and immediately outside the home. This paper is concerned only with results for NO_2.

Nitrogen dioxide

NO_2 is a common atmospheric pollutant, produced when there is combustion of fossil fuels in air. The most important sources in outdoor air are the combustion of fossil fuels for power generation and in vehicles. In homes, NO_2 in the air comes both from outdoor air and from the combustion of heating and cooking fuels within the home. It is also produced by tobacco smoking.

At concentrations normally found in the indoor air, NO_2 is odourless and colourless. The main concern about NO_2 is its possible effects on the respiratory health of children. It may increase the risk of respiratory disease, particularly in people with bronchitis or asthma, and raise individual susceptibility to other harmful environmental factors.

Many organisations throughout the world set standards or guidelines for permitted levels of airborne contaminants, including NO_2. These are based upon levels of pollutants to which people may be exposed without detriment to their health. Most of these standards relate to the workplace, but as more becomes known about the exposure of the population to pollutants in the domestic situation, and the effects on health, it may become possible to determine sensible exposure limits for homes. The World Health Organisation recommends that NO_2 concentrations should not exceed 150 $\mu g/m^3$ (80 parts per billion) over 24 hours[3], based on the lowest concentration known to affect asthmatics.

While the magnitude of any risk from NO_2 in the home, and its dependence on the presence of other risk factors, is not yet established, it is important to gather data on exposure levels so that a risk assessment can ultimately be carried out.

A pilot study undertaken in Northwest England during 1989 confirmed earlier findings that the main factor affecting NO_2 levels in the home is gas cooking[4]. The highest concentration found, in kitchen in a gas-cooking home, was 158.8 $\mu g/m^3$ (85 ppb). The pilot study also showed that the majority of personal exposure was due to NO_2 indoors at home.

Measurements in the pilot (and in ALSPAC) were averaged over 14 days, and therefore did not show peaks. The results of one study of animals suggest that peaks may be more important than the background concentration in determining health effects[5] although the background levels and peaks in this study were greater than any likely to appear in the home. Peaks can only be measured by continuous monitors, which are expensive and impractical to use on a large scale. However, Ross[6] has shown a good correlation between seven-day averaged values measured by passive samplers and the maximum one-hour averaged levels recorded by a continuous chemiluminescent detector in the same room. It may therefore be possible, after further work, to make a realistic estimate of peak NO_2 concentrations in homes from the results of passive sampling.

THE NITROGEN DIOXIDE SURVEY - METHOD

NO_2 levels were monitored, as 14 day time-weighted averages, using passive diffusion tubes (Palmes tubes)[7]. These small plastic tubes have a cap at each end. One cap holds two stainless steel mesh discs impregnated with a chemical (25 mg triethanolamine) which adsorbs NO_2 from the air. A cap on the other end of the tube is removed to allow air to enter; this cap is replaced at the end of the sampling period.

In each home, NO_2 measurements were taken in the kitchen, living room, mother's bedroom and immediately outside the home. One tube was placed at each location except for the kitchen, where there were two tubes for greater precision, since previous work has indicated that the main indoor source of NO_2 is gas cooking[4]. For the statistical analysis, the average value of the two kitchen measurements was used. Samples were taken every three months, so each home which completed the survey provided four batches over twelve months. The month of commencement was staggered so that each month was covered by approximately one third of the homes. In addition, data on outdoor ambient levels were obtained from the Bristol City Council.

Some analysis was conducted on the basis of seasonal, rather than monthly, levels (Spring = March, April and May; Summer = June, July and August; Autumn = September, October and November; Winter = December, January and February).

RESULTS

Reliability

The correlation between the two kitchen measurements over the whole sample and all batches was $r=0.85$ ($p<0.01$). This is a measure of the overall reliability of the measurement method. Approximately 3% more variance in living room levels is explained when using the mean kitchen level, compared with using one of the individual kitchen measurements, indicating that the reliability of the measurement was slightly increased by taking the mean.

Outdoor compared with indoor concentrations

The mean and standard deviation for each month and sampling location are shown in Table 1. Table 2 shows the percentage frequencies of grouped NO_2 levels.

Table 1. Means and standard deviations of NO_2 concentrations by month (ppb)

	Kitchens		Living rooms		Bedrooms		Outdoors	
Month	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
January	24.5	24.6	16.2	21.8	16.0	13.1	25.3	10.5
February	21.5	19.1	15.0	10.7	11.7	8.2	25.7	13.4
March	23.4	21.0	19.2	20.1	13.2	10.6	21.3	13.8
April	20.5	15.7	15.7	13.2	11.9	9.4	16.4	6.3
May	15.8	8.6	11.9	5.8	12.0	14.8	15.8	6.0
June	20.6	15.1	19.0	12.5	18.0	22.6	18.0	11.3
July	16.4	9.3	14.3	7.4	12.3	6.2	14.5	7.0
August	21.8	11.1	20.0	21.4	15.1	6.9	19.3	9.3
September	17.0	10.0	13.9	9.0	13.1	8.6	18.2	9.3
October	20.0	17.1	14.5	10.2	14.3	9.9	24.4	11.6
November	23.8	29.3	15.5	14.2	17.3	24.5	26.4	13.4
December	18.6	16.1	16.7	17.2	11.3	10.8	27.9	14.9

Table 2. Percentage frequencies of NO_2 levels by month

	Kitchens			Living rooms			Bedrooms			Outdoors		
ppb	0 to 29.9	30 to 79.9	80+	0 to 29.9	30 to 79.9	80+	0 to 29.9	30 to 79.9	80+	0 to 29.9	30 to 79.9	80+
Jan	71.1	24.4	4.4	86.7	8.8	4.4	88.9	8.9	2.2	65.9	34.1	0.0
Feb	77.1	23.0	0.0	89.6	10.4	0.0	97.8	2.2	0.0	63.0	37.0	0.0
Mar	74.0	24.0	2.0	81.3	18.7	0.0	92.0	8.0	0.0	77.1	22.9	0.0
Apr	82.8	17.2	0.0	86.2	13.8	0.0	96.6	3.4	0.0	100.0	0.0	0.0
May	91.3	8.7	0.0	97.8	2.2	0.0	97.8	0.0	2.2	97.8	2.2	0.0
Jun	83.6	14.8	1.6	82.0	18.0	0.0	93.3	5.0	1.7	93.3	5.0	1.7
Jul	90.7	9.4	0.0	97.0	3.1	0.0	100.0	0.0	0.0	96.8	3.2	0.0
Aug	74.5	25.6	0.0	90.7	7.0	2.3	97.6	2.4	0.0	90.7	9.3	0.0
Sep	91.7	8.4	0.0	95.8	4.2	0.0	91.7	6.3	2.1	89.5	10.4	0.0
Oct	75.7	24.3	0.0	87.9	12.1	0.0	93.8	6.3	0.0	68.7	31.2	0.0
Nov	77.8	15.5	6.6	85.7	14.3	0.0	88.6	6.9	4.5	50.0	50.0	0.0
Dec	80.4	17.4	2.2	90.8	7.0	2.3	95.5	4.4	0.0	59.1	40.9	0.0

Outdoor levels were higher in autumn and winter than in spring and summer. The higher levels correspond to the seasons when more fossil fuels are being burned. Living room and bedroom levels did not follow the outdoor pattern, varying little in the course of the year. Kitchen levels followed the general pattern of outdoor levels, although with less extreme seasonal variation.

Concentrations were lower indoors than outdoors, except in kitchens in spring and summer. Mean outdoor levels from November through to February were greater than 25 ppb, whereas the mean indoor levels were all lower than this. The modal value fell most frequently between 15 and 25 ppb, although it was lower in March and July and higher in November. The mean outdoor levels showed fewer outlying maximum values than indoor levels.

The correlation between outdoor ambient levels and levels immediately outside the homes was significant ($p < 0.01$) but poor. Values of r for different types of area were 0.29 (rural), 0.27 (suburban), 0.23 (urban) and 0.42 (central urban). This level of association is insufficient for outdoor measurements to be replaced by ambient measurements in this kind of study.

Indoor concentrations

Without exception the mean kitchen concentrations were higher than those in living rooms and bedrooms throughout the year. The modal value in kitchens fell between 5 and 15 parts per billion (ppb) throughout the year, except in August and September, when it was between 15 and 25 ppb. Maximum monthly values varied from 35-45 ppb in summer to 115-125 ppb in November.

As in the case of kitchens, living room concentrations fell most frequently between 5 and 15 ppb, although mean levels were lower than in kitchens. In June the mode rose to between 15 and 25 ppb. In August, the mode was between 5 and 15 ppb, but the mean level was actually higher than in June because of one outlying August value above 135 ppb. Overall, the mean level was highest in summer, when it was very similar to the outdoor level.

Bedroom concentrations fell most frequently between 5 and 15 ppb, except in June when they were most frequently between 15 and 25 ppb. The mean levels in bedrooms reached the mean outdoor level only in June. The slightly higher summer level dropped through autumn to a lower level in winter and spring.

Indoor NO_2 concentrations above WHO guideline

Eleven homes had at least one 14 day mean above the 80 ppb WHO guideline value for 24 hours[3]. It is possible that more homes would have exceeded the 24 hour guideline during a single day. While eleven homes represents only 6% of the sample, this would be about 1,400,000 homes if the same percentage were found in the UK as a whole. It is however, possible that some of the high results could be due to errors of measurement. In contrast with the whole sample, the correlation between the two kitchen measurements was not significant when one or both tubes registered over 80 ppb, suggesting that the samplers are either less accurate at higher concentrations or prone to give false high readings.

The effect of outdoor NO_2 levels on indoor concentration

To examine the effect of outdoor concentrations on indoor NO_2, outdoor concentrations were grouped, and one-way analysis of variance (ANOVA) was performed (see Table 3). In all rooms and seasons, higher mean outdoor NO_2 concentrations were associated with higher mean concentrations indoors, and this relationship was significant in all cases except bedrooms in summer (when concentrations still followed the trend: 10.9, 15.9 and 18.2 ppb respectively for the three outdoor concentration groups). This clearly shows a relationship between indoor and outdoor levels, although the correlations were generally moderate (highest was $r = 0.65$ between kitchen and outdoors for gas-cooking homes in the autumn). Correlations between rooms were generally higher, up to $r = 0.91$ (between bedrooms and living rooms in gas-cooking homes in winter).

Table 3. Mean seasonal indoor concentrations related to outdoor concentration

		Outdoor concentration							
		0-10 ppb		11-20 ppb		>20 ppb			
		Mean	N	Mean	N	Mean	N	F	p<
Kitchens	Spring	12.2^{a}	16	18.8^{b}	71	27.1^{ab}	33	5.4	0.01
	Summer	11.3^{ab}	27	19.8^{a}	59	24.6^{b}	46	10.7	0.01
	Autumn	8.7^{a}	16	12.2^{b}	30	26.7^{ab}	70	9.2	0.01
	Winter	6.8^{a}	10	15.8^{b}	41	26.6^{ab}	79	7.4	0.01
Living rooms	Spring	7.3^{a}	16	14.2^{b}	70	23.6^{ab}	32	8.2	0.01
	Summer	10.6	27	18.5	59	21.4	46	4.6	0.02
	Autumn	6.1^{a}	14	19.6^{b}	29	17.8^{ab}	75	10.5	0.01
	Winter	7.3	8	9.6^{a}	40	20.3^{a}	81	6.7	0.01
Bedrooms	Spring	7.9^{a}	16	11.5	72	17.3^{a}	33	4.2	0.02
	Autumn	6.5^{a}	14	9.2^{b}	30	18.8^{ab}	76	6.2	0.01
	Winter	5.3^{a}	9	6.4^{b}	41	15.1^{ab}	79	11.9	0.01

The means sharing a superscript on any row were significantly different (Tukey tests)

Table 4. NO_2 concentrations (ppb) related to main cooking fuel

		Natural Gas		Electricity			
		Mean	N	Mean	N	t	p<
Kitchens	Spring	29.0	56	12.9	62	5.88	0.01
	Summer	25.4	61	15.4	66	4.72	0.01
	Autumn	28.4	48	15.3	65	3.24	0.01
	Winter	29.7	60	15.8	67	3.95	0.01
Living rooms	Spring	20.1	54	12.6	62	2.70	0.01
	Summer	20.8	61	15.9	66	1.85	(0.07)
	Autumn	16.0	50	14.2	65	0.83	(0.41)
	Winter	19.3	60	13.7	67	1.84	(0.07)
Bedrooms	Spring	14.8	56	10.8	63	1.81	(0.08)
	Summer	19.6	61	12.4	65	2.50	0.02
	Autumn	16.4	51	14.2	66	0.72	(0.50)
	Winter	13.9	61	9.7	66	2.18	0.05

Bracketed p values are not significant

Main cooking fuel

Four fuels were reported as being used as the main cooking fuel: electricity, natural gas, oil and bottled gas. There were too few homes using oil or bottled gas to include them in the statistical analysis. All mean indoor concentrations of NO_2 were higher in homes using gas than in homes using electricity, as shown in Table 4, and most differences were significant. In gas-cooking homes, all seasonal mean kitchen NO_2 levels, and living room levels in spring and summer, were higher than outdoors. Other indoor levels were lower than outdoors. In electric-cooking homes, all mean indoor levels were lower than outdoors.

Two-way ANOVAs (main cooking fuel by outdoor level) were performed on indoor levels for each room and season. The two factors showed no significant interaction in any room or season. Both factors were very significant in kitchens but the outdoor level was more important than cooking fuel in living rooms and bedrooms, except for bedrooms in summer.

Thus, high outdoor levels and gas cooking appear to be important factors in determining indoor levels of NO_2 but the issue of determinants of indoor levels is taken up in more detail in the companion paper[2].

CONCLUSION

The study has provided data on typical levels of NO_2 found in the air of homes in the Avon area. While the homes are not fully representative of the UK housing stock, the results do give a broad indication of the range of levels which can be expected to occur. This risks of having high indoor levels are greater in homes in which cooking is by gas.

The relatively high levels found in a number of homes (i.e. above the WHO guideline level) indicate a need for further assessment of NO_2 levels in homes and the possible health risks. This includes a need to assess the validity of the high NO_2 measurements.

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