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EXPOSURE TO NITROGEN DIOXIDE IN HOMES IN THE UK: A PILOT STUDY

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SUMMARY

The purpose of this study was to pilot a method for investigating typical levels of nitrogen dioxide (NO_2) in homes, and the factors which influence personal exposure to NO_2, in the UK. The pilot was also used to conduct an analysis of the factors which influence indoor levels of NO_2 and personal exposure.

72 homes were selected on the basis of type of area (inner city, suburban or rural) and cooking fuel (gas or electricity). Passive sampling diffusion tubes (Palmes tubes) were used to measure NO_2 concentrations in the bedroom, living room, kitchen and immediately outside the home. In addition, personal exposure was measured by diffusion tubes worn by the occupants. Data on the dwelling and occupants (particularly those undergoing personal monitoring) were obtained using questionnaires and diaries. The survey was carried out in the summer.

The main factors which appear to influence NO_2 levels in the home, and personal exposure, are the use of natural gas for cooking and the number of people in the household. A winter survey might show an effect of heating fuel. Inner city and suburban areas have higher outdoor concentrations than rural areas, but neither area nor outdoor levels significantly affect indoor or personal concentrations.

Personal exposure correlates most highly with habitable room NO_2 levels, and more highly with the living room measurement than the kitchen or bedroom measurements. These results probably reflect the amount of time spent in each room (more being spent in living rooms than in kitchens) and higher concentrations in living rooms than in bedrooms. The number of hours spent in

the bedroom, hours away from home outdoors, and the kitchen NO_2 concentration add to the variance explained, to a total of 50%. This represents about 69% of the reliable variance.

Approximately 70-75% of personal exposure to NO_2 was calculated to be due to exposure indoors at home. In homes with electric cooking the main source of exposure to NO_2 was probably the outdoor air.

1. INTRODUCTION

Nitrogen dioxide (NO_2) is a common atmospheric pollutant, produced in small quantities when there is combustion in air. The main indoor sources in homes are gas cooking and any heating system which involves combustion without adequate removal of combustion gases - principally unflued gas or oil heaters and solid fuel fires.

Research suggests that high exposure to NO_2 can be detrimental to lung function, particularly in children and bronchitic or asthmatic individuals, and can increase sensitivity to other environmental factors such as tobacco smoke, although the evidence for any such effects in UK homes is not clear. The implications of exposure to NO_2 have recently been reviewed by a European working group (COST, 1989).

Because there have been concerns about the possible health effects of long-term exposure to low levels of NO2, the Department of the Environment commissioned a study of NO_2 exposure in the UK, commencing with a pilot study. The purpose of the pilot was to establish a method for investigating typical levels of NO_2 and the factors which influence personal exposure to NO_2. The pilot was also used to conduct an analysis of the factors which influence indoor levels of NO_2 and personal exposure.

2. METHOD

Three areas were chosen from the Greater Manchester region to represent inner city, suburban and rural environments. Approximately 100 addresses were randomly selected in each area. An initial visit by interviewers to these addresses was used to recruit volunteers, and to obtain information regarding the type of fuel they used for cooking and heating. On the basis of this information, 72 homes were selected for the survey, 60 with natural gas cooking only, and 12 (4 in each area) with electric cooking only. Homes with electric cooking had no bottled gas or paraffin heating.

Measurement of NO_2 concentrations in each home was carried out using the Palmes diffusion tube method (Atkins, 1978). Trained interviewers delivered the tubes to each participating household. At each home, one tube was placed in the bedroom, living room and just outside the home, and two tubes in the kitchen. The tubes were normally positioned at about adult head height (in homes with young children the tubes were positioned where children could not reach them). Tubes were not positioned directly next to window openings, or directly above gas fires or stoves. The outside tubes were not placed directly adjacent to the flues of gas boilers, or near to a garage or where a car was normally parked.

In addition, two individuals (Person A and Person B) in each household were asked to wear a personal sampler. This involved clipping a Palmes tube to the outer garment and transferring the tube to the outer layer of clothing with each change of clothing. The householder was instructed that the tube should be worn all the time, even when in the home. At night and at other times when the tube had to be taken off it was clipped to a stand and kept nearby. Where possible, the two individuals were the person most in the home and the person least in the home. Monitoring in each home was continuous over a two week period in the summer of 1989, and the tubes were successfully returned to the laboratory by being posted by the householder.

In 18 households (12 with gas cooking, 6 with electric) triplicate tubes were placed close together in each location in order to assess the precision of the measurement method. Supplies of diffusion tubes doped with known amounts of NO_2, supplied by a third party laboratory, were analysed in order to provide an independent check on the precision of the analysis. Unexposed tubes were incorporated into the analytical procedure in order to calculate a mean blank value for correction of results. All concentrations are expressed as micrograms of NO_2 per cubic metre ($\mu g/m^3$).

In addition to placing the tubes, the interviewer carried out a structured interview with one member of the household to complete the main questionnaire. This questionnaire provided data on the home (e.g. number of rooms, type of heating system), cooking and ventilating habits and sociodemographic variables. Each person who wore a personal sampler completed a second questionnaire and was requested to keep a daily diary of his/her activities. The tubes were exposed in each household for a period of two weeks. At the end of this period, the interviewer revisited the home to collect the diffusion tubes and the diaries.

3. RESULTS AND DISCUSSION

3.1 Response

Of the 72 homes recruited to take part in the study, two declined to participate when re-contacted. A further two homes failed to return the exposed diffusion tubes. Full results were therefore obtained for 68 homes. This represents a very good return rate of 94.4%.

3.2 Quality assurance

Table 1 shows the results of analysis of the doped tubes, which were labelled A, B and C. Overall, the level of error is about 5%. Translated into reliability, the results mean that the maximum possible correlation between the measured level and any other variable is r=0.975 (except by chance). The mean level found in the blank tubes analysis was 0.008 (S.D.=0.004).

TABLE 1. RESULTS ($\mu g/m^3$ NO_2) OF DOPED TUBE ANALYSIS.

	TUBES A	TUBES B*	TUBES C
LEVEL STATED BY LAB	0.30	0.82	1.55
MEAN MEASURED LEVEL	0.311	0.801	1.512
S.D.	0.0084	0.0337	0.0356
CONFIDENCE LIMITS			
90%	0.297-0.325	0.746-0.857	1.453-1.571
95%	0.294-0.328	0.735-0.867	1.442-1.582
90% AS % OF MEAN	+/- 4.50	+/- 6.93	+/- 3.90
95% AS % OF MEAN	+/- 5.47	+/- 8.24	+/- 4.63
*THIS ANALYSIS EXCLUDED ONE VALUE OF 0.234 WHICH SEEMED TO BE DUE TO A SPECIFIC ERROR RATHER THAN MERE IMPRECISION			

Table 2 shows the results of triplicate analysis of tubes. In the case of kitchen and outdoor levels, the measurement reliability (expressed as a correlation coefficient) is almost as high as that of the doped tube analysis. This indicates that little error results from the placing of the tubes and transfer of tubes from exposure site to laboratory. In contrast the bedroom and living room measurements have quite poor reliability, suggesting that duplicate tubes should be used at these locations if high reliability is required.

The reasons for the difference between kitchens/outdoors and living rooms/ bedrooms are far from clear. The specification was that the tubes should be placed a maximum of 6 inches apart, so it is unlikely that the true exposures would have been very different. Also, uncapping and recapping should have been carried out at the same time for each triplicate set. There is no obvious reason why the analysis should have been more reliable for tubes from different rooms. It is possible that the difference is due to chance but it would be useful to conduct further work to verify the triplicate findings.

TABLE 2. RESULTS ($\mu g/m^3$ NO_2) OF TRIPLICATE ANALYSIS

PLACE	MEAN	POOLED S.D.	RELIABILITY	% RELIABLE VARIANCE
KITCHEN	40.9	6.64	0.947	89.7
LIVING ROOM	30.8	6.00	0.709	50.3
BEDROOM	27.0	3.07	0.751	56.4
OUTDOOR	20.7	2.53	0.940	88.3

3.3 Relationships among NO_2 levels

The concentrations measured in the different locations around each home were all significantly correlated with each other (Table 3), but outdoor concentrations were not significantly correlated with any of the indoor or personal concentrations

TABLE 3. CORRELATIONS BETWEEN NO_2 LEVELS ($\mu g/m^3$)

		r*	N
Living Room (LRNO2) with:	BNO2	0.36	67
	KNO2	0.39	68
	PNO2	0.53	108
Bedroom (BNO2) with:	KNO2	0.30	67
	PNO2	0.35	106
Habitable Room (HNO2) with:	PNO2	0.56	108
Kitchen (KNO2) with:	PNO2	0.43	108
All Rooms (RNO2) with:	PNO2	0.53	108

* All $p<0.01$

HNO2 = Habitable rooms mean value (BNO2 & LRNO2)
RNO2 = All rooms mean value (HNO2 & KNO2)
PNO2 = Personal (Persons A & B pooled)

Outdoor concentration is related to area (Table 4). There is little difference between the inner-city and suburban areas, but both areas have higher concentrations than rural areas ($F=10.41$, $df=63,2$, $p<0.001$). This is as one would expect because in rural areas there is less pollution from traffic, chimneys etc. The indoor and personal concentrations showed no significant relationship with area.

TABLE 4. RELATION OF OUTDOOR CONCENTRATION ($\mu g/m^3$) TO AREA

	Frequency within stated range					
AREA	0-10	10-20	20-30	30-40	40+	Mean
INNER CITY	0	9	9	4	2	25.3
SUBURBAN	0	9	8	3	2	23.9
RURAL	4	13	1	0	0	14.3

There are two results here which, on first examination, seem surprising: (a) indoor and outdoor levels are not significantly correlated (b) rural and non-rural areas differ in outdoor levels but not indoor levels.

There are several possible explanations for these results. First, the mean outdoor levels are higher in non-rural than in rural areas, but there would normally be a tendency to ventilate less when outdoor pollution (including noise) is higher. This tendency can be seen in the lower ventilation in non-rural areas (Table 5) - kitchen and bedroom windows are more likely to be open all day in rural areas (Fisher's test, $\chi^2=14.31$, $df=1$, $p<0.001$). In addition, it is likely that some NO_2 is adsorbed by surfaces and furnishings in buildings. Therefore non-rural householders, when indoors, have less contact with the outside air than rural householders do, and the non-rural outside concentration consequently has a lower effect on personal exposure. Second, outdoor concentrations were (in this sample) higher for homes which had electric cooking, and therefore lower indoor production of NO_2 (see 3.4). Finally, within each area, any effect of outdoor levels on personal exposure could be masked by the indoor production of NO_2.

TABLE 5. WINDOW OPENING HABITS RELATED TO AREA

Number of homes in which windows are open

	Kitchen		Bedroom	
When open	Non-rural	Rural	Non-rural	Rural
Most of day	17	18	29	17
Part of day	19	1	18	0
As required	9	2	4	1
Never	6	0	0	2

3.4 Significant effects on NO_2 levels

Analysis of variance (ANOVA) and correlational analysis were used to identify those factors which have a significant statistical relationship with NO_2 levels. The main factor which was shown to influence the levels of NO_2 in the home, and personal exposure, is the use of gas for cooking, as shown in Table 6. The use of gas for the oven, hob and grill would contribute to high kitchen levels, which would in turn raise the levels in other rooms. The length of time for which gas is used for cooking at weekends also has a significant effect on kitchen levels.

The NO_2 levels recorded are shown in Table 7. The health implications of these results are difficult to state with certainty until further work has been carried out, and in particular it is important to establish the nature of any interactions with other environmental factors and of peak exposures (COST, 1989). The remainder of this paper is about the factors which contribute to exposure in the home rather than the possible effects on health.

Where there is electric cooking, the levels are very similar outdoors, in the kitchen and in other rooms. This suggests that there are minimal other indoor sources of NO_2 in these homes. The mean NO_2 measurement in kitchens with gas cooking is over twice as high as in those with electric cooking. This large difference may distort the statistical analysis of other variables, since in such a small sample there could be a chance relationship between gas cooking and other variables. Therefore further analysis was carried out using only the homes in which gas was the main cooking fuel.

TABLE 6. THE EFFECT OF COOKING FUEL ON NO_2 LEVELS ($\mu g/m^3$)

Fuel used for main oven

	Gas		Electricity			
	Mean	N	Mean	N	t	p<
Living room	38.5	54	24.6	13	5.08	0.01
Habitable rooms	34.1	54	25.0	13	3.48	0.01
Kitchen	60.7	54	28.1	13	6.62	0.01
All Rooms	47.4	54	26.5	13	6.51	0.01
Person A	31.7	45	23.9	9	5.03	0.01
Mean of A & B	32.7	51	26.7	11	3.74	0.01
Outdoor	20.5	50	26.6	13	2.14	0.05

Fuel used for hob

	Gas		Electricity			
	Mean	N	Mean	N	t	p<
Living room	39.6	30	21.4	6	3.00	0.01
Habitable	34.4	30	24.8	6	2.35	0.05
Kitchen	64.8	30	25.7	6	6.64	0.01
All rooms	49.7	30	25.3	6	6.71	0.01
Person B	34.5	21	26.6	4	2.94	0.02

Fuel used for grill

	Gas		Electricity			
	Mean	N	Mean	N	t	p<
Bedroom	29.8	54	24.0	11	2.21	0.05
Living room	38.5	54	23.2	12	6.30	0.01
Habitable	34.1	54	23.7	12	3.95	0.01
Kitchen	60.7	54	25.6	12	8.27	0.01
All rooms	47.4	54	24.6	12	8.74	0.01
Person A	31.7	45	23.6	8	5.21	0.01
Person B	33.6	42	27.7	10	2.75	0.02
Mean of A & B	32.7	51	26.1	10	4.30	0.01

Number of hours gas is used for cooking per day at weekend

Kitchen NO_2 level ($r=0.23$, $n=56$, $p<0.05$)
All rooms NO_2 level ($r=0.23$, $n=56$, $p<0.05$)

Neither the main nor the secondary form of heating had a significant effect on NO_2 levels in gas-cooking homes. This finding must be seen in the context that the survey was carried out in the summer, when most heating systems would not have been in use; a winter survey might show an effect of heating fuel.

The size of the household emerged as the most important factor other than cooking fuel (Table 8). The more people there were in the household, the higher the bedroom, living room and habitable room NO_2. It might be assumed that more people simply means that more cooking is done. However, the kitchen level itself is not significantly increased in larger households, which suggests that some secondary factor is responsible. For example, in larger households there might be a greater tendency to leave doors open around the house, which would decrease the kitchen level but increase other levels. Future surveys could include a question about this.

TABLE 7. MEAN AND VARIATION OF NO_2 LEVELS ($\mu g/m^3$)

		NO_2 Concentration, $\mu g\ NO_2/m^3$			
MAIN OVEN GAS	n	Mean	S.D.	Min	Max
Bedrooms	54	29.8	8.1	13.8	53.6
Living rooms	54	38.5	13.5	20.6	76.3
Mean of bedroom and living room	54	34.1	8.8	18.7	57.6
Kitchen	54	60.7	29.6	21.7	158.8
Mean of all rooms	54	47.4	16.6	21.0	95.0
Outdoors	50	20.5	8.3	7.1	48.7
Person A	45	31.7	8.8	15.3	63.9
Person B	42	33.6	9.9	12.3	59.2
MAIN OVEN ELECTRIC					
Bedroom	12	25.4	8.0	14.6	40.5
Living rooms	13	24.6	7.3	15.6	41.5
Mean of bedroom and living room	13	25.0	6.8	15.8	41.0
Kitchens	13	28.1	10.1	19.6	58.5
Mean of all rooms	13	26.6	8.2	18.1	49.8
Outdoors	13	26.6	12.1	9.8	51.0
Person A	9	23.9	2.5	21.0	27.6
Person B	11	28.7	5.7	21.9	39.1

The remaining significant results for gas-cooking homes are shown in Table 9. These results can be regarded as less important for 2 reasons: (a) each variable affects only one or two measurements and (b) there is no a priori basis for expecting these results. The following discussion indicates those results from which something might be concluded.

The only effect of ventilation devices, ventilation behaviour or draughtiness was that opening windows at night, other than in the main rooms, was associated with increased NO_2 concentrations, particularly in the kitchen. This may seem surprising, but the occupant is more likely to ventilate the home if the air quality is poor or if there is condensation. Either or both of these could be statistically associated with higher NO_2 levels.

NO_2 levels were higher for respondents who had been living for a longer time in their present home. This is not related to larger households resulting from a longer stay: correlations were increased, not decreased by partialling out household size and two further effects became significant (living room $r=0.31$, $n=51$, $p<0.02$; habitable rooms $r=0.28$, $n=51$, $p<0.025$). It is possible that people who have been living a longer time at the same home have an older cooker, which produces more NO_2, but no information is available on this.

TABLE 8. HOMES WITH GAS AS THE MAIN COOKING FUEL: THE EFFECT OF HOUSEHOLD SIZE ON NO_2 LEVELS ($\mu g/m^3$)

Total number of people in household

Bedroom concentration ($r=0.29$, $n=54$, $p<0.02$)
Living room concentration ($r=0.42$, $n=54$, $p=0.001$)
Habitable rooms concentration ($r=0.46$, $n=54$, $p<0.001$)

Number of people in household aged 16 or over

Bedroom concentration ($r=0.40$, $n=54$, $p=0.001$)
Living room concentration ($r=0.36$, $n=54$, $p<0.005$)
Habitable rooms concentration ($r=0.46$, $n=54$, $p<0.001$)

Number of people at home on weekday evenings

Bedroom concentration ($r=0.30$, $n=54$, $p<0.02$)
Living room concentration ($r=0.56$, $n=54$, $p<0.001$)
Habitable rooms concentration ($r=0.56$, $n=54$, $p<0.001$)
All rooms concentration ($r=0.24$, $n=54$, $p<0.05$)

Number of people at home at weekends

Living room ($r=0.44$, $n=53$, $p<0.001$)
Habitable rooms ($r=0.42$, $n=53$, $p=0.001$)
Person A concentration ($r=0.27$, $n=44$, $p<0.05$)
Person B concentration ($r=0.31$, $n=42$, $p<0.05$)

TABLE 9. HOMES WITH GAS AS THE MAIN COOKING FUEL: OTHER SIGNIFICANT EFFECTS ON NO_2 LEVELS ($\mu g/m^3$)

Are windows in other rooms (other than kitchen, bathroom, living room, dining room, respondent's bedroom) open during the night?

	Yes		No			
	Mean	N	Mean	N	t	p<
Kitchen	88.6	8	55.3	38	3.06	0.005
All rooms	63.6	8	44.6	38	3.11	0.005

For how long has the respondent been living in the home?

Kitchen concentration (r=0.40, n=54, p=0.001)
All rooms concentration (r=0.40, n=54, p=0.002)

3.5 Contribution of indoor levels to personal exposure

The previous section reported the building and household factors which are related to NO_2 levels and personal exposure. Further analysis was conducted on the whole sample in order to determine the contribution of NO_2 levels in different locations to personal exposure. The populations Person A and Person B were pooled to give one large sample (PNO2).

The NO_2 level in each location, multiplied by the hours a person spends there, gives an estimate of total personal exposure. These estimates correlate well with actual measured personal exposure (PNO2), but less well than do the simple measured levels of NO_2 (Table 10). The reduced level of correlation would be due to the reduced number in the sample and the imprecision of the estimates of time spent in each location.

PNO2 correlates most highly with habitable room NO_2, and more highly with the living room NO_2 level than the level in the kitchen or bedroom. These results probably reflect the fact that more time was spent in living rooms than in kitchens, and there were higher levels in living rooms than in bedrooms. The hours spent away from home have an inverse relationship with personal exposure.

A multiple regression analysis was then performed with PNO2 as the dependent variable (Table 11). In this procedure, independent variables from a specified list are entered one at a time into an equation which predicts the value of the dependent variable (PNO2). The independent variables are entered into the equation in the order which explains most variance in PNO2 at each step. Included as independent variables were the NO_2 levels in each location, the hours spent in each location and the estimated exposures. Habitable room concentration appeared first in the equation, followed by hours spent in the bedroom, hours away from home outdoors and kitchen concentration.

TABLE 10. MEASUREMENTS MOST HIGHLY CORRELATED WITH PERSONAL EXPOSURE (PNO2)

	r*	N
Habitable rooms concentration (HNO2)	0.56	108
Living room concentration (LRNO2)	0.53	108
All rooms concentration (RNO2)	0.53	108
Hours x HNO2	0.49	98
Hours x RNO2	0.46	98
Hours x concentration**	0.46	91
Hours x LRNO2	0.46	98
Kitchen concentration (KNO2)	0.43	108
Bedroom concentration (BNO2)	0.36	106
Hours outdoors not home	- 0.31	98
Hours travel car/bus/lorry	- 0.30	98
Hours x BNO2	0.23	96
Hours in room not kit or bed	0.23	98
Hours x KNO2	0.22	98

*All p<0.01

**Sum of hours x concentrations for all rooms and outdoors near to home.

TABLE 11. RESULTS OF MULTIPLE REGRESSION ANALYSIS OF PNO2

% of sample	r^2	Variables in equation	B	Constant
100	0.32	Habitable rooms concentration	0.49	
	0.40	Hours in bedroom	-0.01	
	0.43	Hours outdoors away from home	-0.02	
	0.47	Kitchen concentration	0.06	30.5
90	0.33	Habitable rooms concentration	0.50	
	0.40	Hours in bedroom	-0.01	
	0.44	Hours outdoors away from home	-0.02	
	0.47	Kitchen: hours x concentration	1.26x10-4	33.5
80	0.32	Habitable rooms concentration	0.50	
	0.41	Hours in bedroom	-0.02	
	0.45	Hours outdoors away from home	-0.02	
	0.48	Hours spent travelling	-0.02	42.8
70	0.31	Hours x concentration*	1.63x10-4	17.2

*Sum of hours x concentrations for all rooms and outdoors near to home.

The analysis was repeated, excluding first the 10% of people who spent least time indoors at home, and then 20%. Results were similar to those from the whole sample. For the 70% who spent most time indoors at home, the only variable in the equation was the sum of estimated exposures in all rooms and outdoors at home (Table 11). The fact that only one independent variable entered the equation can probably be explained by the reduced sample size. More important, this finding shows that, for those who spend most time in the home, the estimated exposure is the best predictor of actual personal exposure.

Overall, the results indicate that approximately 50% of the variance in personal exposure can be explained by indoor NO_2 concentrations. The results of the quality assurance analyses suggest that only 50-90% of the variance is reliable, depending on the room being sampled. No direct data are available on the reliability of the personal monitoring, but one report (Houthuijs et al, 1990) suggests reliability in excess of 0.85 (i.e. reliable variance approximately 72%). This would be consistent with a balance of exposure biased towards more time in the living room and bedroom but higher exposure in the kitchen, such that the kitchen contributes about 50% of the indoor exposure.

Assuming 72% reliable variance in measured levels, 50% represents 69% of the reliable variance. This is an estimate of the contribution of indoor exposure at home to variance in total exposure. It is likely to be a low estimate given the uncertainty about the amount of time spent in each location.

The estimated exposures for each person who underwent personal monitoring were used to calculate the proportion of total personal exposure which was due to exposure in the home. The results are shown in Table 12.

Values greater than 100% should ideally not have occurred, but could result from errors in recording time or from being at home mainly when NO_2 levels are less than average (e.g. when no cooking is taking place). Whichever column in Table 12 is used, it is clear that the majority of the people monitored receive over 60% of their total exposure inside the home, and none less than 21%. The modal value for the pooled sample is similar to the median, i.e. approximately 70-75% of the exposure to NO_2 is due to exposure indoors at home.

TABLE 12. ESTIMATED EXPOSURE AT HOME AS % OF TOTAL EXPOSURE

	Frequency		
% range	Person A	Person B	A&B Pooled
	1* 2*	1* 2*	1* 2*
21-30	0 0	2 2	2 2
31-40	3 3	0 0	3 3
41-50	5 3	4 4	9 7
51-60	3 5	5 5	8 10
61-70	14 10	6 5	20 15
71-80	5 10	6 6	11 16
81-90	8 7	6 7	14 14
91-100	6 6	7 6	13 12
>100	9 9	7 8	16 17
Total	53 53	43 43	96 96

*If a person's diary hours did not add up to exactly 336 (i.e. two full weeks), one of two assumptions could be made:

(1) the missing or additional hours were all spent away from the home or (2) they were spent in different locations in proportion to the recorded hours. Therefore two figures are given in each column.

4. CONCLUSIONS

A good response rate can be achieved with the procedures used in this study.

NO_2 levels can be measured with generally good reliability using passive diffusion (Palmes) tubes, but the reliability was suspect for living rooms and bedrooms. It is not clear whether the measurement error is due to variations in levels within rooms or to tubes being uncapped and recapped at the wrong time.

The questionnaire provided data on the dwelling and the household, which was sufficiently reliable to be used to predict NO_2 levels.

Outdoor levels of NO_2 are higher in suburban and inner-city areas than in rural areas, but have no significant effect on indoor levels or personal exposure. Indoor levels in different rooms are inter-correlated, but not so highly that one could substitute for the others.

The main factor affecting indoor levels and personal exposure is gas cooking, with the size of the household as the dominant secondary factor (NO_2 levels were higher with larger households). Heating fuel and appliances, and ventilation, were not significant factors, but the survey was carried out in the summer: they would probably be more significant in a winter survey.

Personal exposure is related most strongly to the mean of the NO_2 levels in the living room and bedroom. Although levels were usually higher in the kitchen, less time was spent there. The amount of time spent in the bedroom and away from the home outdoors, and the NO_2 level in the kitchen, add to the variance explained. the total variance explained by these factors is approximately 50%, which is estimated to be 69% of the reliable variance.

Approximately 70-75% of personal exposure to NO_2 was estimated to be due to exposure indoors at home. This would be an underestimate of the contribution of indoor sources in homes with gas cooking since the calculation included homes with electric cooking, in which the outdoor air was the main source of NO_2 exposure.

All these results refer to mean levels over a period of two weeks. Future studies should seek to establish the peak levels to which people are exposed, since these may have greater significance for health.

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