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Indoor nitrogen dioxide in homes along trunk roads with heavy traffic

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Abstract

***Objectives*—To assess the distribution of indoor nitrogen dioxide (NO_2) concentrations in homes located in differing environments, and to investigate the influence of factors such as automobile exhaust on the indoor environment.**

***Methods*—The concentrations of indoor NO_2 over 24 hours were measured in both the heating and non-heating periods in homes of pupils from nine elementary schools in Chiba, Japan. Information on factors that could influence indoor environments was collected by questionnaire.**

***Results*—Indoor NO_2 concentrations during the heating period were higher in homes with unvented heaters than in homes with vented heaters, although the concentrations varied greatly among homes primarily because of the type of heating device used. During the non-heating period, indoor NO_2 concentrations were significantly higher in homes adjacent to trunk roads than in homes located in other areas. Multiple regression analysis showed that indoor NO_2 concentrations were associated with atmospheric NO_2 in homes with vented heaters during the heating period, and in homes in areas other than on the roadside during the non-heating period. In areas other than the roadside, cigarette smoking in indoor environments also significantly contributed to indoor NO_2. The average concentrations of indoor NO_2 in the homes of pupils attending each school were significantly related to the atmospheric NO_2 in areas other than the roadside. However, the relation between indoor and atmospheric NO_2 concentrations was not significant in roadside areas.**

***Conclusions*—These findings suggest that indoor NO_2 concentrations are related to the atmospheric NO_2 and type of heating appliances, and are also affected by automobile exhaust in homes located in roadside areas.**

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Keywords: nitrogen dioxide; air pollution; indoor environment

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Recently, increasing automobile traffic in Japan has caused considerably higher levels of air pollution derived primarily from automobile exhaust.[1 2] Nitrogen dioxide (NO_2) is one of the main pollutants in automobile exhaust, and the atmospheric concentration of NO_2 is higher in areas adjacent to major trunk roads with heavy traffic than in the general environment.[2 3] The potential effect of NO_2 on the health of residents who live near trunk roads is a matter of concern.[4–6]

Nitrogen dioxide is also produced by the use of combustion appliances in homes,[7] and its concentration may exceed that outdoors in homes with unvented heating appliances.[7 8] Therefore, in evaluating the effects of automobile exhaust on human health, additional indoor environmental effects—such as the use of heating appliances—should be considered.[9–11] Several studies have assessed the indoor or personal exposure concentrations of NO_2 in homes adjacent to trunk roads, as a risk factor for respiratory health.[2 3] Because of methodological problems and inadequate sample size, however, these studies have not sufficiently elucidated levels of indoor air pollution.

To evaluate the effects of various environmental factors on respiratory health, we have been conducting a series of epidemiological surveys in school children.[12 13] In this study, we measured indoor NO_2 concentrations in the homes of school children living in areas that contain major trunk roads. We investigated the relations between these measurements and indoor environmental factors such as type of heating appliances used, atmospheric levels of air pollution, and distance of the home from the trunk road.

Materials and methods

SUBJECTS

The subjects of this study were 1029 fourth grade pupils (aged 9–10 years) attending nine elementary schools in various regions of Chiba Prefecture, Japan. Of these schools, six are located in urban areas, and their school districts are intersected by major trunk roads that are all national highways or motorways. The daytime average traffic densities of these roads ranged from about 17 000 to 82 000 vehicles every 12 hours in 1990; heavy vehicles accounted for 26.8% of the traffic at that time. One of the remaining three schools was located in a suburban area, and the other two schools were in rural areas. In each of these cases, there were no major roads within the school district.

The annual average concentrations of NO_2 in 1993, measured by Saltzman's method,[14] at ambient air monitoring stations in the vicinities of these schools, were 26–32 ppb for urban areas, 20 ppb for suburban areas, and 7–11 ppb for rural areas. The greatest distance between a school and the monitoring station was 3 km for one rural school, whereas the distances were 0–1.2 km for the other eight schools. In January and June 1991, we measured the 24 hour

Table 1 Number of homes with available measurement of indoor NO_2, by area, period, and type of heaters used in winter

District	Initial subjects	*Heating period* Homes with unvented heaters	Homes with vented heaters	Total (n (%))	Non-heating period (n (%))
Urban areas:					
0–49 m from major roads	94	49	34	83 (88.3)	77 (81.9)
≥50 m from major roads	543	307	192	499 (91.9)	472 (86.9)
Suburban area	130	99	26	125 (96.2)	120 (92.3)
Rural areas	262	185	58	243 (92.7)	236 (90.1)
Total	1029	640	310	950 (92.3)	905 (87.9)

average outdoor NO_2 with badge type samplers (Toyo Roshi, Tokyo, Japan) at several points surrounding these schools.[15 16] In each case, the differences between their concentrations and the NO_2 concentrations obtained on the days at the monitoring station near the school were within ±10%.

MEASUREMENTS OF INDOOR NO_2 CONCENTRATIONS

In October 1992, a standard respiratory symptom questionnaire, the modified Japanese version of ATS-DLD-78-C,[17] was sent to all the subjects. It was completed by either their parents or guardians. The questionnaire covered the respiratory symptoms of the children, the structure of the house and window frames, and the indoor environments of the home. Measurements of indoor NO_2 concentrations were carried out in each subject's home on two occasions, in January or February 1993 (heating period) and in June or July 1993 (non-heating period), by which time the subjects had become fifth grade pupils. Indoor NO_2 concentrations were measured with badge type samplers.[15] Badges were distributed along with booklets, after a detailed verbal explanation for use at the schools. The subjects were instructed to take them home, break the seal, and place them on top of the television set in the living room. After the badges had been left for 24 hours, they were sealed in aluminium packs and collected. The badges, including blanks, were analysed spectrophotometrically, and the 24 hour average concentrations of NO_2 (ppb) were recorded. The sensitivity of the badge is 66 ppb per hour, and the accuracy is within ±20%.[15]

The measurement time, the number of cigarettes that were smoked by the household members in the room during the measurement period, and the use and type of heating appliances (during the heating period only) were ascertained by questionnaire. The subjects were asked to identify their heating appliance from among five types, and the presence or absence of an exhaust outlet was confirmed with illustrations of various shaped outlets.

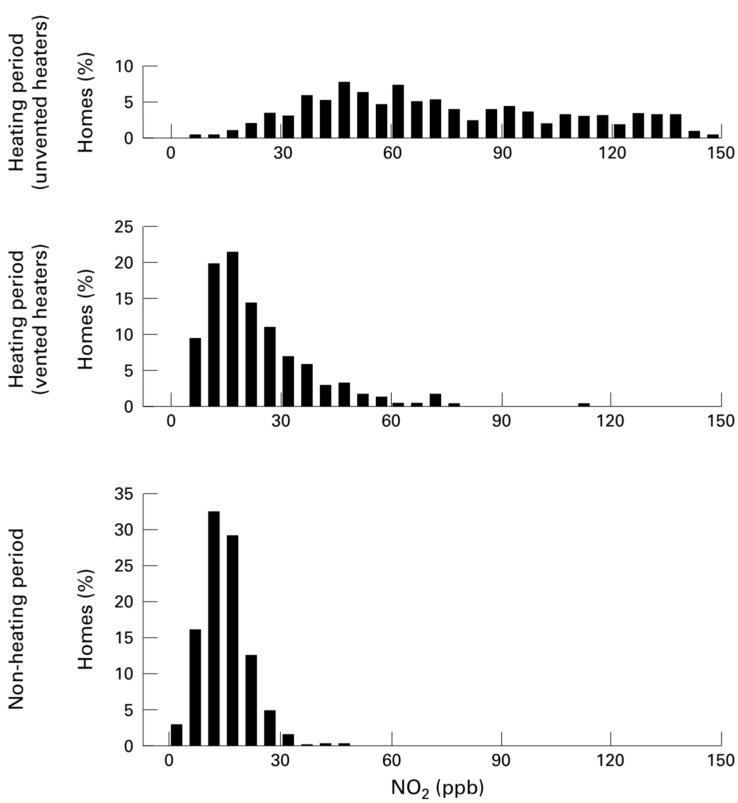

Figure 1 Distribution of indoor NO_2 concentrations by period and type of heaters used in winter.

DATA ANALYSIS

For pupils from the six urban schools, the distance between their homes and the trunk roads was measured on maps. The subjects were then classified into two groups: homes <50 m from the edge of trunk roads (roadside area) and those ≥50 m from the roads (non-roadside area). Indoor NO_2 concentrations in each period were compared for the four areas: roadside, non-roadside, suburban, and rural. Significance was evaluated by analysis of variance (ANOVA), followed by Turkey's method. Comparisons relative to the other factors were conducted by Student's *t* test.

The influences of the various factors were evaluated with multiple regression models with indoor NO_2 concentrations as the dependent variable. The atmospheric NO_2 concentrations, whether one cigarette or more were smoked in the room during the measurement period, the structure of the house, and the type of window frames were included in the models as independent variables. The 24 hour average of NO_2 concentrations obtained on the day of our measurements at the monitoring station near each school were used as the atmospheric NO_2 concentrations. These analyses were conducted separately for the measurement period, the type of heaters (during the heating period only), and the distance from trunk roads. Moreover, we calculated the average concentration of NO_2 in the homes of pupils in each school in each period, and evaluated the correlation with the atmospheric NO_2 concentrations. For urban

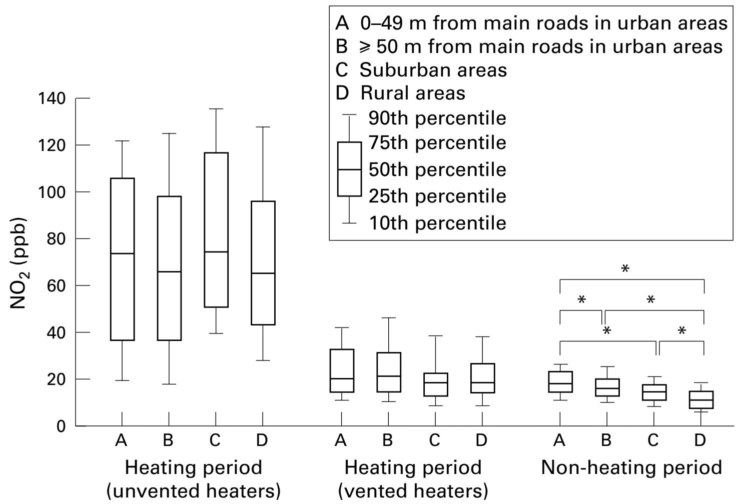

*Figure 2 Distribution of indoor NO_2 concentrations by location of homes, period, and type of heaters used in winter. * $p < 0.01$.*

schools, the concentrations were calculated for the roadside and non-roadside homes, respectively.

Results

NUMBER OF SUBJECTS AND DISTRIBUTION OF INDOOR NO_2 CONCENTRATIONS

The badges were collected from 1022 homes (99.3%) for the heating period, and 1006 homes (97.8%) for the non-heating period. In 22 of these homes for both periods, information on the structure of the house and window frames was not complete. Homes in which the measurement time was unclear, 22 hours or less, or 26 hours or more, were excluded (heating period, 50 homes; non-heating period, 79 homes). Thus, the final sample for analysis comprised 950 homes for the heating period and 905 for the non-heating period. During the heating period, 640 homes used unvented heaters, and 310 homes used vented heaters (table 1).

The indoor NO_2 concentrations by period and type of heaters showed a skewed distribution (fig 1). The geometric mean in the heating period was higher in homes with unvented heaters (geometric mean: 66.4 ppb, range: 5–172 ppb) than in homes with vented heaters (20.6 ppb, 6–112 ppb). In the non-heating period, the geometric mean of indoor NO_2 concentrations was lower (13.8 ppb) than in the heating period, and the range was smaller (2–47 ppb).

INDOOR NO_2 CONCENTRATIONS BY AREA

Figure 2 shows the distributions of indoor NO_2 concentrations by area and period. The medians in homes with unvented heaters during the heating period were 73 ppb for the roadside area, 66 ppb for the non-roadside area, 73 ppb for the suburban area, and 64 ppb for the rural area. The values in homes with vented heaters were 20, 21, 19, and 19 ppb, respectively, and were lower than in homes with unvented heaters. The differences among the four areas were not significant in homes with unvented or vented heaters. The medians of indoor NO_2 concentrations during the non-heating period were 18, 16, 15, and 11 ppb, respectively. The value was significantly lower in the rural area than in the other areas. The value in the roadside area was significantly higher than in the non-roadside and suburban areas, whereas the difference between the non-roadside and suburban areas was not significant.

Table 2 shows the indoor NO_2 concentrations relative to smoking in the room, structure of the house, and type of window frames. Cigarette smoking in indoor environments significantly increased the indoor NO_2 concentrations during the non-heating period. The effect of indoor smoking was also shown in homes with unvented heaters during the heating period, although such an effect was not found in homes with vented heaters. The indoor NO_2 concentrations during the non-heating period were significantly higher in steel or reinforced concrete houses than in wooden houses. During the heating period, however, there were no differences relative to the structure of the house, in both homes with unvented and vented heaters. In the houses with unvented heaters during both the heating and the non-heating period, the indoor NO_2 concentrations were significantly higher in houses with aluminum window frames than in those with wooden windows. However, no significant difference due to the type of window frames was detected in homes with vented heaters during the heating period.

MULTIVARIATE ANALYSIS OF INDOOR NO_2 CONCENTRATIONS

The multiple regression analyses of various factors on the indoor NO_2 concentrations were conducted separately for the measurement period, the type of heaters, and the distance from trunk roads (table 3). In homes with unvented heaters during the heating period, no factor significantly contributed to indoor NO_2 in

Table 2 Mean concentrations (ppb) of indoor NO_2 in relation to smoking in the home, structure of the house, and type of window frames

	Heating period								
	Homes with unvented heaters			*Homes with vented heaters*			*Non-heating period*		
	n	*Mean (SEM)*	*p Value*	*n*	*Mean (SEM)*	*p Value*	*n*	*Mean (SEM)*	*p Value*
Smoking in home:									
Yes	327	78.2 (1.9)	0.005	144	23.6 (1.1)	0.651	429	15.8 (0.3)	0.010
No	313	70.7 (1.9)		166	24.3 (1.2)		476	14.7 (0.3)	
Structure of house:									
Steel or reinforced concrete	186	71.4 (2.4)	0.136	154	23.9 (1.1)	0.876	321	17.1 (0.3)	<0.001
Wood	454	75.8 (1.6)		156	24.1 (1.3)		584	14.2 (0.3)	
Window frames:									
Aluminium	589	76.2 (1.4)	<0.001	299	24.0 (0.9)	0.749	845	15.3 (0.2)	0.042
Wood	51	55.9 (3.9)		11	22.6 (4.5)		60	13.6 (0.7)	

Table 3 Results of multiple regressions of ambient NO_2 concentration, smoking at home, structure of the house, and window frames on indoor NO_2 concentrations (ppb)

	Heating period								*Non-heating period*			
	Homes with unvented heaters				*Homes with vented heaters*							
Variable	*Coef*	*SE*	*Std coef*	*p Value*	*Coef*	*SE*	*Std coef*	*p Value*	*Coef*	*SE*	*Std coef*	*p Value*
Distance from trunk roads 0–49 m:												
Intercept	26.664				−4.688				17.283			
Ambient NO_2 concentration (ppb)	1.066	0.536	0.277	0.053	0.673	0.309	0.380	0.038	−0.014	0.116	−0.015	0.902
Smoking in home*	12.169	8.746	0.189	0.171	3.755	5.594	0.121	0.507	0.919	1.180	0.091	0.439
Structure of house†	−15.592	9.038	−0.243	0.092	9.419	6.158	0.270	0.137	−1.659	1.216	−0.163	0.177
Window frames‡	12.016	31.156	0.053	0.702	−1.736	16.493	−0.019	0.917	2.627	5.204	0.059	0.615
Others:												
Intercept	51.642				17.101				9.110			
Ambient NO_2 concentration (ppb)	0.041	0.140	0.012	0.770	0.262	0.083	0.192	0.002	0.251	0.027	0.315	<0.001
Smoking in home*	6.573	2.747	0.097	0.017	−1.296	1.740	−0.044	0.457	0.990	0.407	0.078	0.015
Structure of house†	−5.931	3.148	−0.078	0.060	−2.548	1.802	−0.087	0.158	1.756	0.461	0.131	<0.001
Window frames‡	21.600	5.008	0.178	<0.001	0.818	4.741	0.010	0.863	−0.066	0.805	−0.003	0.934

Regression analysis was conducted separately for the type of heater, the measurement period, and the distance from trunk roads.
Coef=regression coefficient; SE=standard error of the regression coefficient; Std coef=standardised regression coefficient.
*Yes=1; no=0.
†Steel or reinforced concrete=1, wood=0.
‡Aluminium=1, wood=0.

the roadside area, but the effects of cigarette smoking in the room and the type of window frames were significant in the areas other than the roadside. In homes with vented heaters, atmospheric NO_2 concentrations significantly contributed to indoor NO_2 in both areas. During the non-heating period, atmospheric NO_2 concentrations, cigarette smoking in the room, and the structure of the house were significantly related to indoor NO_2 for homes located in areas other than the roadside. Of these, the effect of the atmospheric NO_2 concentration was the most significant factor. However, no factor was significant in homes located in the roadside area.

Figure 3 shows the relations between the atmospheric NO_2 and the average concentrations of NO_2 in each period in the homes of pupils attending each school. During the heating period, the average concentrations in homes with unvented heaters were not related to the atmospheric NO_2 in either the roadside area or areas other than the roadside. In homes with vented heaters, however, a significant relation was found between the mean values of indoor NO_2 and the atmospheric concentrations in these two areas. During the non-heating period, the average concentrations of indoor NO_2 were significantly related to the atmospheric concentrations in homes located in areas other than the roadside, although no such relation was found for those in the roadside area.

Discussion

Epidemiological studies have shown that exposure to NO_2 increased the prevalence of respiratory symptoms and diseases in children,[18 19] although the findings have not been entirely consistent.[9 10] The atmospheric concentrations of NO_2 are higher in areas adjacent to main roads with heavy traffic than in the general environment.[2 3] Consequently, there has been concern about the effects of automobile exhaust on the health of people who live near main roads. Recently, several studies have reported a high prevalence of respiratory symptoms in people who lived along main roads.[4 5 20] This has caused particular concern in Japan, where many homes front on to trunk roads with heavy traffic.[2 3]

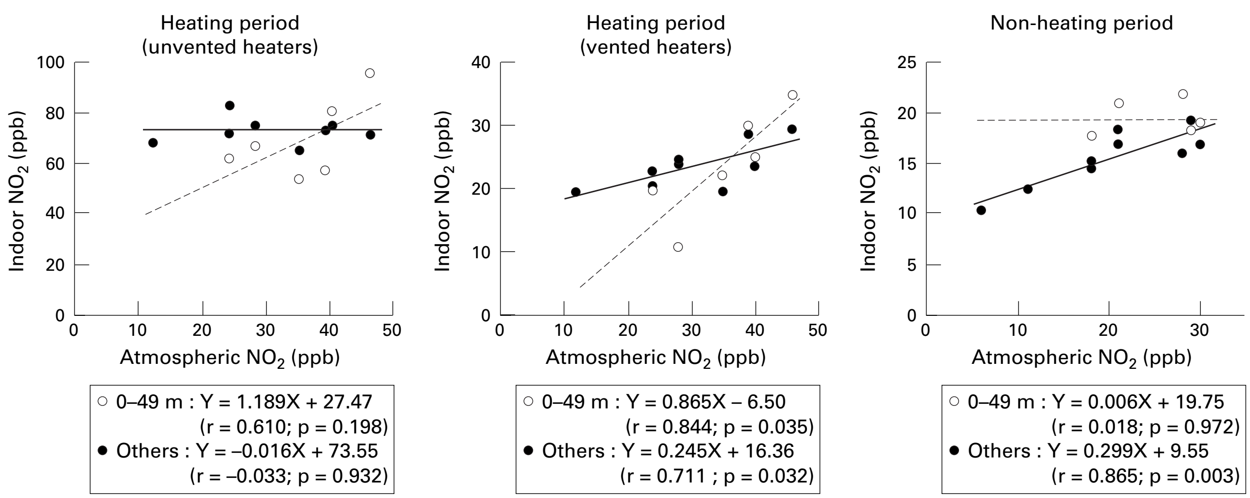

Figure 3 Relations between the mean of indoor NO_2 concentrations and atmospheric NO_2 concentrations by distance from roads and period. The points on the graphs represent groups of pupils from each school, and the data for pupils attending the urban schools with homes <50 m from a trunk road were analysed separately.

Indoor sources of NO_2 that cause indoor air pollution are regarded as environmental factors.[7 8 21] To evaluate the potential health effects of outdoor and indoor NO_2, direct measurement of personal exposure concentrations is considered desirable.[22] Passive diffusion monitors for NO_2 have been used in epidemiological studies, but few of these studies have dealt with many subjects.[18] In large scale epidemiological investigations, measurements of indoor NO_2 concentrations, which are assumed to contribute greatly to personal exposure,[23 24] have often been carried out as an alternative.[9 25 26]

Numerous investigations have shown that indoor NO_2 concentrations may be high in homes with unvented combustion appliances, particularly gas or kerosene heaters.[7–9 25] The present study also showed that indoor NO_2 concentrations during the heating period were extremely high in homes with unvented heaters. We had previously reported that indoor NO_2 concentrations were found to be more than 100 ppb in some homes even with vented heaters, and indicated that surveys that used questionnaires could lead to misclassification of the type of heating appliance.[16] In the present study, the use and type of heating appliance were ascertained by the same questionnaires used in previous surveys.[16] Also, the presence or absence of an exhaust outlet was confirmed by illustrations of various outlets. The indoor NO_2 concentrations were <80 ppb in the homes that reported using vented heaters, with the exception of only one home, and both the mean value and range were smaller than those reported in the previous study. It seems that confirming the presence or absence of an exhaust outlet with illustrations is a more appropriate method than simply inquiring into the type of heating appliances used. In homes with unvented heaters, the variation in indoor NO_2 concentrations was notably high. This may be due to the hours of use of heating appliances and the distance between the heaters and the NO_2 samplers. Additional consideration about the use of heaters is needed to evaluate the variation in indoor NO_2 during the heating period.

The effects of the airtightness of dwellings on indoor NO_2 concentrations were evaluated. During the non-heating period, the indoor NO_2 concentrations were significantly higher in steel or reinforced concrete houses than in wooden houses. During the heating period, however, no difference was found relative to the structure of the house. Nakai *et al*[3] found no consistent association between the structure of the house and indoor NO_2 concentrations, although they showed that the concentrations differed by the types of house structure. The relation between structure of the house and indoor NO_2 should be further evaluated.

In homes with unvented heaters during the heating period, the indoor NO_2 concentrations were higher in homes with aluminium window frames than in those with wooden window frames. In homes with vented heaters, however, there were no differences relative to type of window frames, which were similar results to those obtained by Nakai *et al*[3] and Ono *et al*.[27] Multiple regression analysis showed that aluminium window frames were significantly associated with higher indoor NO_2 concentrations only in homes with unvented heaters during the heating period. The airtightness of houses with aluminium window frames seems to increase indoor NO_2 concentrations in the presence of indoor sources—such as unvented heating appliances.

The use of gas cooking stoves and pilot lights has also been known to increase indoor NO_2 concentrations, particularly in the kitchen.[21 28 29] Although almost all homes in Japan use gas appliances for cooking, gas stoves with pilot lights are rarely used.[3 27] Therefore, although ventilation rates, size, and layout of dwellings should be considered,[30] we did not obtain detailed information on these factors. Further study will be needed to determine the effects of gas cooking appliances in Japanese homes.

There have been numerous reports on the effects of cigarette smoking on NO_2 concentrations. Koo *et al*[30] and Adgate *et al*[31] found no relation between the intensity of smoking and personal exposures to NO_2. In contrast, Leaderer *et al*[8] and Goldstein *et al*[28] reported that the presence of smokers in the household increased indoor NO_2. Klus *et al*[32] found that the nitric oxide (NO) concentration increased in a room during smoking without an increase in NO_2 concentrations, and that the concentration of NO_2 rose once the smoking had stopped. In the present study, cigarette smoking in indoor environments was associated with higher concentrations of NO_2 in homes with unvented heaters during the heating period, and the relation was also significant during the non-heating period. Also, multiple regression analysis showed that cigarette smoking increased indoor NO_2 concentrations in the homes located in areas other than the roadside.

It has been shown that the atmospheric NO_2 concentrations were highest at the edge of trunk roads and decreased with the distance from the roadside.[2 3] Although such variations in NO_2 concentrations depend on the road structure, adjacent buildings, and atmospheric conditions,[33] the concentrations have been known to decrease gradually up to a distance of 50 m from the roadside, and not to vary further away.[2] Nakai *et al*[3] and Ono *et al*[27] reported that indoor NO_2 concentrations were higher in homes <20 m from the roadside than in those further away. In the present study, the homes <50 m from the edge of roads were classified as roadside homes when considering the number of subjects and the variations in NO_2 concentrations relative to distance from the roads. Consequently, indoor NO_2 concentrations for each area during the non-heating period decreased according to the following factors: roadside, non-roadside, suburban, and rural areas, which corresponded to the respective atmospheric NO_2 concentrations in the areas.

Rutishauser *et al*[34] found a high correlation between indoor and outdoor NO_2 concentrations. Dockery *et al*[35] and Sexton *et al*[36] showed that indoor NO_2 concentrations could be estimated from the outdoor NO_2 concentrations and type of gas cooking stoves. In the areas other than the roadside, the relation between atmospheric NO_2 and concentrations of indoor NO_2 in the homes of pupils attending each school was significant for those homes in which vented heaters were used during the heating period: the relation was also shown during the non-heating period. In roadside areas, this relation was significant only in homes in which vented heaters were used during the heating period, but it was not apparent during the non-heating period.

Multiple regression analysis also showed that the proportions of variation in indoor NO_2 that are explained by atmospheric NO_2 concentration differed relative to the type of heater, the period, and the distance from trunk roads. These results suggested that the atmospheric air pollution due to automobile exhaust also contributed to the variation in indoor NO_2 in the roadside areas. In homes with unvented heaters during the heating period, there was no relation between indoor and atmospheric NO_2 concentrations in either area. This is probably because the variation due to the use of unvented heaters was so great as not to distinguish the effect of the atmospheric air pollution.

The presence of other pollutants—such as particulate matter and formaldehyde—in the indoor environment should be also considered to contribute to human health, but simple monitors suited for epidemiological studies are unavailable for pollutants other than NO_2.

In conclusion, this study showed that indoor NO_2 concentrations were affected considerably by the use of unvented heaters during the heating period, and that the mean values of indoor NO_2 in the homes of pupils attending each school were related to atmospheric NO_2 concentrations. Multiple regression analysis also showed that the indoor NO_2 concentrations were associated with atmospheric concentrations in homes with vented heaters during the heating period, and similarly during the non-heating period. Indoor NO_2 concentrations were higher in homes in roadside areas than in the other areas, during the non-heating period. These findings suggested that indoor NO_2 concentrations reflect the effect of automobile exhaust. However, the relation between indoor and outdoor NO_2 concentrations was not clear in homes in roadside areas. In this study, each measurement was carried out on only one day during both the heating and non-heating periods. Also, only six schools formed the subject of roadside areas. The relation between indoor and outdoor NO_2 concentrations in roadside areas should be further evaluated.

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