Indoor and outdoor nitrogen dioxide concentration in residential houses in Australia

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ABSTRACT

As part of a larger indoor environmental study, residential indoor and outdoor levels of nitrogen dioxide (NO_2) were measured for 14 houses in a suburb of Brisbane, Queensland, Australia. Passive samplers were used for 48-h sampling periods during the winter of 1999. The average indoor and outdoor NO_2 levels were 13.8 ± 6.3 and 16.7 ± 4.2 ppb, respectively. The indoor/outdoor NO_2 concentration ratio ranged from 0.4 to 2.3, with a median value of 0.82. The results of statistic analyses indicated that there was no significant correlation between indoor and outdoor NO_2 concentrations, or between indoor and fixed site NO_2 monitoring station concentrations. However, there was a significant correlation between outdoor and fixed site NO_2 monitoring station concentrations. There was also a significant correlation between indoor NO_2 concentration and indoor submicrometre (0.007–0.808 μm) aerosol particle number concentrations. The results in this study indicated indoor NO_2 levels are significantly affected by indoor NO_2 sources, such as a gas stove and cigarette smoking. It implies that the outdoor or fixed site monitoring concentration alone is a poor predictor of indoor NO_2 concentration.

INDEX TERMS

Air pollution; Indoor air quality; Submicrometre particles

INTRODUCTION

Nitrogen dioxide (NO_2) is the secondary oxidation product of nitric oxide in the atmosphere. NO_2 air pollutant has significant sources in both the indoor and outdoor environments. Health impacts of NO_2 include respiratory irritation, increased susceptibility to respiratory infection and lung development impairment (Jones, 1999). As a major indoor pollutant, NO_2 concentration indoors, and the relationship between the indoor and outdoor concentrations of NO_2 have been investigated for decades (Yocom, 1982; Monn, 2001). The main finding of these two studies, namely that gas stoves, outdoor air and the season (due to changes in ventilation) are the most important parameters influencing indoor NO_2 levels, were confirmed in all other studies (Monn 2001). However, these results also indicted that the relationship between indoor levels and personal exposures was associated with geographical conditions, indoor sources and other demographic characteristics. Despite the extensive research of outdoor air pollutants carried out in Australian cities (Manins, 2000), the data for indoor NO_2 levels and sources in residential houses in Australia is relatively limited (Garrett *et al.*, 1999; Lee *et al.*, 2000).

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As part of a large study investigating indoor air, the purpose of this present study was: (1) to investigate the characteristics of indoor and outdoor NO_2 levels in 14 residential houses in Brisbane, Australia; (2) to investigate the correlation between indoor NO_2 concentrations and indoor submicrometre (in the range from 0.007 to 0.808 μm) particle number concentrations.

METHOD

Sampling Site and Houses

The sampling site and house information in this study is described in detail by Morawska *et al.* (2001). Briefly, a residential suburb (Tingalpa) of Brisbane was chosen as the measurement site. The site has reasonably flat topography and there is a good mix of house type, both in terms of age and of style, i.e. newer and older houses, brick and timber, high set and low set. Fourteen houses in the suburb were chosen for the study. The relevant information about house characteristics is provided in Table 1.

Sampling Protocol

The measurements were conducted between May and July 1999, which is wintertime in Brisbane. Passive samplers were used for NO_2 concentration measurements. The sampler used was a badge-type unit described by Yanagisawa and Nishimura (1982). For indoor measurements, the sampler was placed in the living room more than 2 m from windows and 3 m from sources, and facing upwards. Simultaneously, a TSI Model 3022A Condensation Particle Counter (CPC) (TSI Incorporated, St Paul, MN, USA) was placed nearby to measure total submicrometre (in the range from 0.007 to 0.808 μm) particle number concentrations. For outdoor NO_2 measurements, the sampler was placed outside more than 1 m above the ground and out of the rain. An exposure time of more than 48 h for all samplers was employed.

The quality of NO_2 measurements was assured by blanks from each house (indoor and outdoor) to account for differences in sealing quality and lag time before analysis. Once sampling was completed, the NO_2 passive badges were analysed by a spectrophotometer (Beckman Model DU640). In addition, for comparison purpose, two fixed monitoring stations' NO_2 concentration data were collected. One station (City Station) is situated on the sixth floor of a building in the Gardens Point Campus, Queensland University of Technology (QUT), within the Brisbane CBD. Another station (Eagle Farm Station) is located about 5 km north of the sampling site (Tingalpa). All statistical analyses were conducted using a statistical analysis software package, SPSS for Windows version 10 (SPSS Inc.).

RESULTS

A summary of the measurement results of indoor and outdoor NO_2 concentrations, as well as the submicrometre particle number concentrations are given in Table 1.

Table 1 Summary of average indoor, outdoor and fixed site monitoring stations' nitrogen dioxide concentrations, the Indoor/Outdoor nitrogen dioxide concentration ratio (I/O), Indoor/City monitoring station nitrogen dioxide concentration ratio (I/City), Indoor/Eagle Farmer monitoring station nitrogen dioxide concentration ratio (I/EF), as well as the indoor total submicrometre particle number concentrations (particles $cm^{-3} \times 1000$)

ID	Height	Walls	Stove	Smoke	Indoor NO_2 (ppb)	Outdoor NO_2 (ppb)	Indoor particle	I/O ratio	I/City ratio	I/EF ratio
h03	L	B	E	No	8.7	17.1	16.9	0.51	0.85	0.57
h04	H	B	E	No	16.1	26.6	16.9	0.60	1.03	0.84
h05	L	B	E	Yes	18.4	23.7	22.4	0.77	1.15	0.82
h06	L	B	E	No	10.8	14.7	13.6	0.74	1.29	0.90
h07	H	T	E	No	13.2	14.7	14.6	0.90	1.31	1.60
h08	H	T	E	No	12.3	15.5	17.7	0.79	0.99	0.84
h09	H	T	E	No	10.5	15.0	15.8	0.70	0.96	0.91
h12	H	T	E	Yes	11.1	12.9	17.4	0.86	2.02	1.52
h13	L	T	G	No	32.9	14.4	27.2	2.28	–	4.38
h14	L	B	E	No	8.8	10.4	16.2	0.84	0.83	0.67
h15	H	T	G	No	14.0	16.4	19.8	0.85	1.43	0.93
h16	H	T	E	No	7.3	19.2	14.3	0.38	0.56	0.35
h17	H	T	E	Yes	15.0	16.4		0.91	1.12	0.92
h18	L	B	E	No	14.6	16.4	23.5	0.89	–	0.82
Average					13.8	16.7	18.2			
S.D					6.3	4.2	4.0			
Median					12.8	16.0	16.9	0.86	1.08	0.87
Max					32.9	26.6	27.2	2.28	2.02	4.38
Min					7.3	10.4	13.6	0.38	0.56	0.35

Note: L, Lowset; H, Highset; B, Brick; T, Timber, E, Electric; G, Gas.

The average (±SD) residential indoor and outdoor NO_2 levels were 13.8 ± 6.3 and 16.7 ± 4.2 ppb, with median values of 12.8 and 16.0, respectively. The indoor/outdoor NO_2 concentration ratio ranged from 0.4 to 2.3, with a median value of 0.82. However, all indoor/outdoor ratios for these houses were less than one with the exception of one house (House 13). The median ratios of indoor concentrations to the two fixed station NO_2 concentrations were higher than the indoor to outdoor ratios, with median values of 1.08 (indoor/City monitoring station) and 0.87 (indoor/Eagle Farmer monitoring station).

The results of statistic analyses indicated that there is no significant correlation between indoor and outdoor NO_2 concentrations, or between indoor concentrations and the two fixed site monitoring station NO_2 concentrations. However, there were significant ($p = 0.03$, $p = 0.02$) correlations between outdoor concentrations and the two fixed site monitoring station NO_2 concentrations. There were also significant ($p < 0.001$) correlations between indoor NO_2 concentrations and indoor total submicrometre aerosol particle number concentrations.

From Table 1, it could be seen that the indoor NO_2 concentration in House 13 (32.9 ppb) was significantly higher than the average concentration level (18.8 ppb). The main reason for this result could be the use of a gas stove in House 13 and that it is a lowset house. The mean

indoor NO_2 concentration in houses with gas stoves was 23.4 ppb, compared with 12.2 ppb for houses without. For houses with electric stoves, the mean indoor NO_2 concentration in houses with a resident smoker was 14.8 ppb, compared with 11.4 ppb for houses without smokers.

DISCUSSION

Indoor NO_2 concentration levels in some Australian residential houses have been investigated in a few studies. Dingle *et al.* (1992) found that the indoor mean 4-day average level was 28 ppb in Perth, Western Australia, which was slightly higher than the outdoor levels of 24 ppb. Garrett *et al.* (1999) monitored indoor and outdoor NO_2 concentration levels using passive samplers in 80 homes, in the Latrobe Valley, Victoria. They found that the overall indoor annual median was 6 ppb, with a mean of 8 ppb. They also found that mean indoor levels were higher than outdoor levels, and a seasonal variation was evident, with the highest levels recorded in winter. The major indoor NO_2 sources reported in their study were: gas stoves, vented gas heaters and smoking. Lee *et al.* (2000) measured indoor and outdoor NO_2 concentrations and personal NO_2 exposures for 57 subjects from six offices located in Brisbane, Queensland. They reported that mean indoor and outdoor NO_2 concentration levels were 10.5 and 14.5 ppb, respectively, with the indoor/outdoor ratio less than one. In the present study, the mean indoor and outdoor values were higher than the results of Garrett *et al.* (1999) and the results of Lee *et al.* (2000), but were lower than the results of Dingle *et al.* (1992). These differences may be the result of geographical variation and sampler variation.

Previous studies in the literature show that gas stoves and smoking were the major indoor NO_2 sources. For example, in a study by Monn *et al.* (1997) of 17 homes in Switzerland, the indoor to outdoor ratios were determined for PM_{10}, $PM_{2.5}$ and NO_2 under natural ventilation conditions. They found that NO_2 I/O ratios (measured using passive samplers of metal grids coated with triethanolamine) for homes with no sources were <1, while homes with gas stoves had ratios larger than 1.2. The results in the present study support their findings.

Chan and Hwang (1996) examined the representativeness of an urban air monitoring station to particular outdoor sites and to some indoor locations. The parameters measured were PM_{10}, CO, SO_2, O_3, NO_2, NO_x, NO, total hydrocarbons (THC), and non-methane hydrocarbons (NMHC). The station was found to be well representative of the outdoor concentrations of all pollutants for the measured period of three weeks. However it was not representative of the indoor NO_2 concentrations. Our result is similar to the results of Chan and Hwang (1996). It implies that outdoor or fixed monitoring concentrations alone are a poor predictor of indoor NO_2 concentration.

CONCLUSION

The results of the present study show that the indoor to outdoor NO_2 concentration ratio varied from house to house and was significantly affected by indoor NO_2 sources, such as the use of a gas stove and smoking. Normally, the indoor to outdoor NO_2 concentration ratio was less one when there were no indoor NO_2 sources.

The results of statistic analyses on the data indicated that there is no significant correlation between indoor and outdoor NO_2 concentrations, or between indoor concentrations and fixed site monitoring station NO_2 concentrations. However, there were significant correlations between outdoor concentrations and fixed site monitoring station NO_2 concentrations. It implies outdoor or fixed site monitoring concentrations alone were a poor predictor for indoor NO_2 concentration. A significant correlation was found between indoor NO_2 concentration and indoor submicrometre aerosol particle number concentration. It supported the idea that ultrafine (<0.1 μm) particles are expected to behave in a similar manner to NO_2.

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