Estimation of Nitrogen Dioxide Source Generation and Ventilation Rate in Residence Using Multiple Measurements in Korea

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Abstract

Indoor air quality can be affected by indoor sources, ventilation, decay and outdoor levels. Alt hough technologies exist to measure these factors, direct measurements are often difficult. Th e purpose of this study was to develop an alternative method to characterize indoor environme ntal factors by multiple indoor and outdoor measurements. Daily indoor and outdoor NO2 con centrations were measured for 30 consecutive days in 28 houses in Brisbane, Australia, and fo r 21 consecutive days in 37 houses in Seoul, Korea. Using a mass balance model and regressi on analysis, penetration factor (ventilation rate divided by the sum of ventilation rate and dep osition constant) and source strength factor (source strength divided by the sum of ventilation rate and deposition constant) were calculated using multiple indoor and outdoor measurement s. Subsequently, the ventilation rate and NO2 source strength were estimated. Geometric mea ns of ventilation rate were 1.44 ACH in Brisbane, assuming a residential NO2 deposition cons tant of 1.05 hr-1, and 1.36 ACH in Seoul, with the measured residential NO2 deposition const ant of 0.94 hr-1. Source strengths of NO2 were 15.8 ± 18.2 μg/m3·hr and 44.7 ± 38.1 μg/m3·h r in Brisbane and Seoul, respectively. In conclusion, indoor environmental factors were effecti vely characterized by this method using multiple indoor and outdoor measurements.

Introduction

Indoor air quality is the dominant contributor to total personal exposure because most people spend a majority of their time indoors (Spengler et al., 1994). Especially when indoor environments have sources of contaminants, exposure to indoor air can potentially pose a greater threat than exposure to ambient air. Changes in construction designs and the increased use of synthetic products may result in an increasing number of complaints about the quality of indoor air, both at home and in the workplace (Jones, 1999). Indoor air quality is affected by outdoor air pollution, indoor generation of pollutants, pollution depletion mechanisms (surface deposition and chemical decay), ventilation, and volume of the indoor space. Although technologies exist to measure these factors directly, it is not practical to directly measure all the factors in field studies.

The purposes of this study were to characterize indoor air quality using multiple NO2 measurements, to estimate ventilation rate and NO2 source strength, and to compare the indoor air quality characteristics in Brisbane, Australia to those in Seoul, Korea. The two cities have many different characteristics such as house type, weather, industry and ambient pollution levels.

Methods

To estimate the ventilation rate and NO2 source strength in indoor environments, daily indoor and outdoor NO2 concentrations for 30 houses in Brisbane were measured over 30 consecutive days between April and May in 1999. In Seoul, daily indoor and outdoor NO2 concentrations in 40 houses were measured for 21 consecutive days between June and August in 2000. In addition, information on house characteristics was collected by identical questionnaires in the two cities.

A mass balance model is often used to explain indoor air quality. Indoor air quality models using mass balance are a useful tool to quantify the relationship between indoor air pollution levels, ambient concentrations, and explanatory variables (Ott et al., 1996). Models of indoor air quality describe the transport and dispersion of pollutants throughout a structure and the variation of indoor air pollutants as a function of source strengths, air change rates, removal mechanisms, and other factors. Considering a residence as a single chamber (one-compartment), a mass balance in the chamber provides,

$$\frac{dC_i}{dt} = mIC_o + S - mIC_i - \frac{R}{V} \qquad (1)$$

Where, Ci= indoor concentration (μg/m3), Co= outdoor concentration (μg/m3), I= ventilation rate (hr-1), S= source strength (μg/m3·hr) = emission rate (μg/hr)/volume of the space (m3), R= decay rate (μg/hr), m= mixing factor (unitless), and V= volume of the space (m3).

The removal rate, R, is a function of a deposition constant (K, hr-1) and the volume of pollutant present indoor (VCi).

$$R = KVC_i \qquad (2)$$

Assuming that the indoor environment is completely mixed (m=1), equation (1) becomes.

$$\frac{dC_i}{dt} = IC_o + S - IC_i - KC_i \qquad (3)$$

Assuming that indoor level is in a steady-state condition (dCi/dt=0), the equation (4) can be obtained.

$$C_{i(ss)} = (\frac{I}{I+K})C_o + (\frac{S}{I+K}) \qquad (4)$$

where, Ci(ss) = average steady-state indoor NO2 concentration.

Substituting I/(I+K) for A and S/(I+K) for B, rearranging terms allow the average concentration of the house to be written as a linear regression equation.

$$C_{i(ss)} = AC_o + B \qquad (5)$$

Because we measured indoor and outdoor concentrations simultaneously, linear regression an alysis provided A and B of equation 5. In equation 5, the penetration factor, A, should be betw een zero and 1. The source strength factor, B, should be greater than or equal to zero because S is greater than or equal to zero.

Results

Geometric means of indoor and outdoor daily NO2 concentrations in Brisbane were 22.6 μg/m3 and 29.3 μg/m3, respectively. The mean ratio of indoor to outdoor (I/O) NO2 concentrations was 0.82 ± 0.41. Daily NO2 measurements were completed in 37 houses for 21 consecutive days in Seoul. Geometric means of indoor and outdoor daily NO2 concentrations in Seoul were 58.9 μg/m3 and 71.0 μg/m3, respectively. The mean ratio of indoor to outdoor NO2 concentrations was 0.88 ± 0.32. The indoor and outdoor NO2 concentrations measured in Seoul were significantly higher than those in Brisbane ($p<0.05$). Indoor and outdoor NO2 concentrations in both cities were log-normally distributed.

Indoor and outdoor NO2 levels were analyzed to determine significant factors of exposure. The presence of a gas range was the most significant factor contributing to indoor NO2 concentration in Brisbane. The mean indoor NO2concentration in houses with a gas range in Brisbane was 34.9 μg/m3, compared with 19.7 μg/m3 for homes with an electric range. Mean ratios of indoor to outdoor NO2 concentrations in homes with electric and gas range were 0.7 ± 0.3 and 0.9 ± 0.3, respectively. No house characteristics had significant associations with indoor NO2 levels in Seoul. It may be due to the fact that all study houses in Seoul have gas ranges. No variables were significantly associated with outdoor levels in the two cities.

Penetration factor (ventilation rate divided by the sum of ventilation rate and deposition constant) and source strength factor (source strength divided by the sum of ventilation rate and deposition constant) were calculated using equation (5) and multiple daily indoor and outdoor NO2 concentrations. Mean coefficients of determination (R2) between daily indoor and outdoor NO2 measurements in both cities are also shown in Table 4. Coefficients of determination for houses with electric ranges was were significantly higher than those for houses with gas ranges ($p<0.05$). Penetration factors were between zero and 1 except for one house in Brisbane and the source strength factors were more than zero in all houses in Brisbane and Seoul. The house in Brisbane with a penetration factor of 1.10 was excluded in the following analysis. Penetration factors in Brisbane were 0.59 ± 0.14. Source strength factors in Brisbane were 1.49 ± 1.25 in homes with electric ranges and 5.77 ± 3.55 in homes with gas ranges and the two were significantly different ($p<0.05$). In Seoul, penetration factors and source strength factors were 0.58 ± 0.12 and 9.12 ± 4.50, respectively. While penetration factors were not significantly different between the two cities, source strength factor in Seoul was significantly higher than that in Brisbane ($p<0.05$).

The relationship between the coefficient of determination (R2) of equation (5) and source strength factor were plotted in Figure 1. Mean R2 with an electric range was significantly higher than that with a gas range ($p<0.05$). Mean R2 with a gas range in Brisbane and Seoul were 0.52 ± 0.20 and 0.57 ± 0.21, respectively, and mean R2 with an electric range in Brisbane was 0.70 ± 0.13. The high correlation with low source strength suggests that the NO2 concentrations inside the houses with electric ranges were more likely influenced by outdoor sources than indoor sources. The houses with electric ranges are located in left-upper part of plot and the houses using gas ranges are sporadically located in right-lower part of plot . High sporadic distribution in gas range houses may indicate the variability in the amount of gas range usage.

Ventilation rate can be estimated from penetration factor and source strength can be estimated from source strength factor, if the deposition constant is known. A NO2 deposition constant of 1.05 hr-1 was assumed for Brisbane, based on several references for Western countries (Wad e et al., 1975; Traynor et al., 1982; Nazaroff and Cass, 1986; Spicer et al., 1989; Spicer et al., 1993; Wikes et al., 1996). Using this deposition constant, the geometric mean ventilation rate was 1.44 ACH with a geometric standard deviation of 1.51 and subsequently, the source stren gth of NO2 was 15.8 ± 18.2 μg/m3·hr. NO2 source strength for houses with electric ranges wa s 6.6 ± 6.3 μg/m3·hr and for those with gas ranges, the NO2 source strength was 29.1 ± 21.8 μ g/m3·hr, as shown in Table 1. The residential NO2 deposition constant has not been measured in Korea. The NO2 deposition constant was calculated by measuring the concentrations of N O2 and CO2 simultaneously in 23 houses in Seoul. The NO2 deposition constant was calculat ed as 0.94 ± 0.21 hr-1. Using the mean NO2 deposition constant of 0.94 hr-1, the geometric m ean ventilation rate was found to be 1.36 ACH with a geometric standard deviation of 1.73 an d, subsequently, the source strength of NO2 was 44.7 ± 38.1 μg/m3·hr. Source strength is dete rmined by dividing emission rate by house volume. In Seoul, a NO2 emission rate of 6,258 μg /hr is estimated using a mean NO2 source strength of 44.7 μg/m3·hr and an average house vol ume of about 140 m3. Similarly, the NO2 emission rate in Brisbane is estimated to be 4,818 μ g/hr by using a mean NO2 source strength of 21.9 μg/m3·hr and an average house volume of about 220 m3.

Table 1. Estimated ventilation rate and NO_2 source strength in Brisbane and Seoul

		Ventilation rate (ACH)		NO2 source strength (ug/m3 hr)	
		Mean±SD (GM, GSD)	Range	Mean±S.D.	Range
Brisbane a	Electric range (n= 16)	1.56±0.64 (1.44, 1.51)	0.71~2.66	6.6±6.3	0.6~21.9
	Gas range (n= 11)			21.9±21.8	9.1~75.2
Seoul b	Gas range (n= 37)	1.58±0.95 (1.36, 1.73)	0.36~4.36	44.7±38.1	8.5~95.9

- GM : Geometric mean

- GSD : Geometric standard deviation

[a]: estimated with NO_2 deposition constant of 1.05 hr^{-1}

[b]: estimated with NO_2 deposition constant of 0.94 hr^{-1}

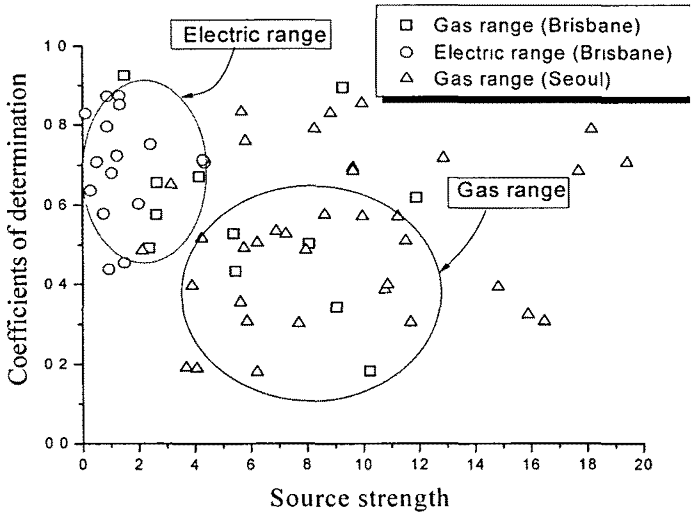

Figure. 1. Relationship between coefficients of determination (R2) and calculated source strength factors in 64 houses in Brisbane and Seoul.

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