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Indoor Air Distribution of Nitrogen Dioxide and Ozone in Urban Hospitals

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Abstract Indoor air pollution has recently become a public concern in Taiwan. People recognize that indoor air quality (IAQ) may be more important than outdoor air quality because they spend over 80% of their time indoors. IAQ could affect health and comfort of building occupants. The objectives of this study are (1) to characterize the indoor concentrations of selected air pollutants at two hospitals in Hsinchu, Taiwan, (2) to evaluate the potential indoor sources of pollutants in these selected hospitals and their indoor/outdoor relationships, and (3) to compare pollutant concentrations with values published in other studies. A significant between-hospital difference in average indoor concentration of nitrogen dioxide and 54.14, 32.69 ppb for Hospital A and B, respectively ($p < 0.05$). Indoor nitrogen dioxide concentration was significantly positively correlated with outdoor nitrogen dioxide concentration, PM_{10} concentration, and traffic flow ($r = 0.91$, 0.65 and 0.72, respectively). The ozone level was also lower in our hospitals than 30 ppb standard.

Keywords Indoor air quality · Nitrogen dioxide · Ozone · Passive sampling

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Indoor air pollution has recently become a public concern in Taiwan. People recognize that indoor air quality (IAQ) may be more important than outdoor air quality because they spend over 80% of their time indoors (Spengler et al. 2001). IAQ (the content of interior air) could affect health and comfort of building occupants. The IAQ may be compromised by microbial contaminants (mold, bacteria), chemicals (such as nitrogen dioxide, ozone), allergens, or any mass or energy stressor that can induce health effects (Salthammer 1999). Recent findings have demonstrated that indoor air is often more polluted than outdoor air (albeit with different pollutants), although this has not changed the common understanding of air pollution (Guo et al. 2004). In fact, the health hazard of indoor air is often greater than that of the corresponding outdoor air. Therefore, IAQ has a greater public health effect. IAQ guidelines, issued by the Environmental Protection Agency of Taiwan in 2005 on the basis of pre-existing guidelines, deal with nine pollutants (Environmental Protection Agency 2005).

Owing to their toxicity, nitrogen dioxide (NO_2) and ozone (O_3) are the main indoor air pollutants mentioned in the guidelines. Nitrogen dioxide causes lung damage (i.e., morphological and physiological changes in pulmonary epithelium) and has genotoxic effects (Hayashi et al. 1987). NO_2 and its derivatives (e.g., peroxynitrite) may induce DNA damage and mutagenesis by oxidizing DNA, deaminating DNA, and inducing the formation of *N*-nitroso compounds (Chuang et al. 2003; Lin and Huang 2004; Noy et al. 1990). Ozone triggers a spectrum of effects that can result in respiratory toxicity. The inhalation of high concentrations of ozone is associated with fatal pulmonary edema (Jaffe 1967). Exposure to ozone can cause injury and inflammation (indicated by cellular and biochemical changes in the lung) (Devlin et al. 1991; Huffman et al.

2001; Thurston and Ito 2001). These changes include increases in activity of lactate dehydrogenase, level of protein, and number of polymorphonuclear leukocytes in bronchoalveolar lavage fluid (Hatch et al. 1994).

Moreover, a significantly high coefficient of correlation (r) was demonstrated between the number of hospitalized chronic obstructive pulmonary disease (COPD) patients and same-day levels of nitrogen dioxide (Fusco et al. 2001). Past studies have focused on outdoor rather than hospital indoor air. The objectives of this study are (1) to characterize the indoor concentrations of selected air pollutants at two hospitals in Hsinchu, Taiwan, (2) to evaluate the potential indoor sources of pollutants in these selected hospitals and their indoor/outdoor relationships, and (3) to compare pollutant concentrations with values published in other studies.

Materials and Methods

Sampling was conducted in two different hospitals in Hsinchu City. One of the selected hospitals is adjacent to a heavily traveled city thoroughfare, while the other is relative far from heavy traffic. The sampling period was 1 month (November, 2006). Samples were collected from the waiting rooms of the two hospitals. The air quality at each location was used to represent the air quality of that particular hospital. Two diffusive passive samplers were used to estimate indoor nitrogen dioxide and ozone levels. The design of the NO_2 sampler was modified Lin's method (Lin and Huang 2004). The collected NO_2 was quantified colorimetrically at 540 nm after using the Griess–Saltzman reaction at 25°C for 15 min. The average recovery of the sampler was 95% (standard deviation, 5%), accuracy was below 10%, and detection limit was 2.0 ppb. The passive sampler for ozone was also modified Pehnec's method (Pehnec and Hršak 2003) and consisted of three rings and a wind screen. Nitrate is formed from the reaction of nitrite ion and ozone. After the sampling, filters were sonicated for 15 min in 15 mL of water and then centrifuged for 10 min. The nitrate ion was analyzed using a ion chromatograph. Anions were separated on an analytical column and a guard column, with 3.5 mM Na_2CO_3/1.0 mM $NaHCO_3$ mixture as an eluent, and their concentrations were monitored using a conductivity detector (Pehnec and Hršak 2003; Zhou and Smith 1997). The ozone concentration was calculated from the nitrate concentration. The limit of detection (LOD) of the O_3 passive sampler was 2.0 ppb and recovery was above 90%.

Mann–Whitney U test was used to compare the average levels of indoor air and indoor/outdoor ratio for NO_2 and O_3 between two hospitals. A multiple regression was performed to assess the relationship between the NO_2 and O_3 levels of hospital indoor air and possible effect variables. The data analysis was performed using SPSS 11.0 for Windows. The criterion for significance was set at $p < 0.05$.

Results and Discussion

Figure 1 shows a significant between-hospital difference in indoor concentration and average indoor concentration of nitrogen dioxide (12.30–75.30, and 9.62–48.80 ppb for Hospital A and B, respectively, and 54.14 and 32.69 ppb for Hospital A and B, respectively; $p < 0.05$). The range of ozone concentration and average ozone concentration paralleled those of nitrogen dioxide (15.00 and 9.70 ppb for Hospital A and B, respectively). The finding that the between-hospital relationship for nitrogen dioxide concentration was similar to that for ozone concentration suggests the two contaminants may have come from outside exhaust fumes. Furthermore, cyclical trend analysis showed that the concentrations of these contaminants inside the hospitals was highest on Monday when the traffic flow was highest in the weekly cycle and was lowest on weekends and holidays, when the traffic flow was lowest. This pattern was especially evident in Hospital A, which was adjacent to a major road. This result is comparable to that of Guo et al. (2004), who found the indoor air quality of markets in Hong Kong was affected by heavy local traffic.

To detect the sources of nitrogen dioxide and ozone inside the hospitals, this research conducted multivariable correlation analysis and an analysis of the ratio of indoor concentration to outdoor air concentration. Table 1 shows the relationships between nitrogen dioxide and ozone concentrations and the variables that influence them. Indoor NO_2 concentration was significantly positively

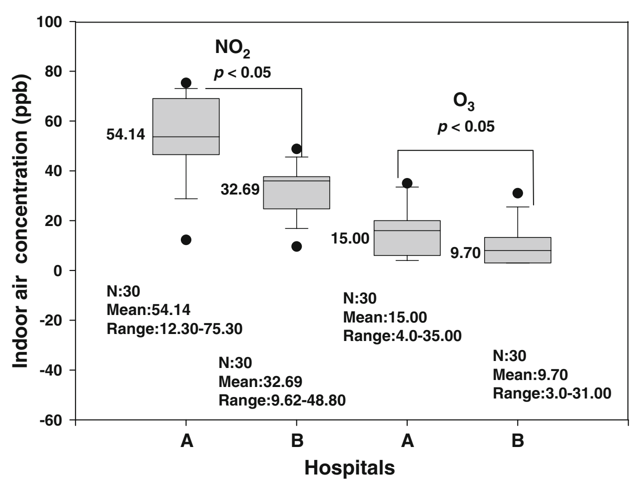

Fig. 1 Distribution of nitrogen dioxide and ozone levels at two hospitals

Table 1 Correlation analysis of selected variables affecting nitrogen dioxide and ozone levels of hospital indoor air

Variables	Indoor NO_2		Indoor O_3	
	Correlation coefficient (*r*)	*p* value	Correlation coefficient (*r*)	*p* value
Outdoor variables				
NO_2	0.91	<0.05	0.29	NS
O_3	0.32	NS	0.89	<0.05
PM_{10}	0.65	<0.05	0.38	NS
Traffic flow	0.72	<0.05	0.41	NS
Rainfall	−0.32	NS	−0.28	NS
Wind speed	−0.22	NS	−0.36	NS
Temperature	0.21	NS	−0.12	NS
Distance to the road	−0.58	<0.05	−0.40	NS
Indoor variables				
Temperature	0.18	NS	0.12	NS
Ventilation rate	0.71	<0.05	0.69	<0.05
Patient number	0.29	NS	0.32	NS

Note: *NS* is not statistically significant ($p > 0.05$)

correlated with outdoor NO_2 concentration, PM_{10} concentration, and traffic flow ($r = 0.91$, 0.65 and 0.72, respectively). In addition, indoor ventilation rate had a clear effect on indoor NO_2 concentration ($r = 0.71$). Indoor ozone level had relationships similar to those of indoor nitrogen dioxide. However, only outdoor O_3 concentration was strongly correlated with indoor ventilation rate. Correlations with other variables were relatively weak. NO_2 and O_3 concentrations were not correlated with each other, indicating the two contaminants neither react nor compete with each other.

Figure 2 shows the indoor to outdoor concentration ratio for nitrogen dioxide and ozone. The I/O average ratio of NO_2 concentration was <1 (0.63 and 0.50 for hospital A and B, respectively), indicating a greater concentration due to outdoor sources, e.g., vehicle exhaust. There was no

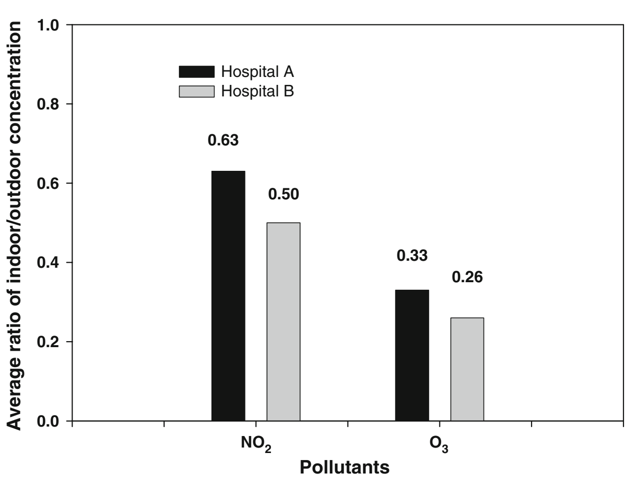

Fig. 2 Average ratio of indoor/outdoor concentration for nitrogen dioxide and ozone at two hospitals

apparent between-hospital difference in I/O ratios, indicating that ventilation rate is another important factor. Since the ventilation rate was higher in Hospital A, which was close to a major road with heavy traffic, than in Hospital B, the two hospitals had similar I/O ratios. Hospital B had a lower ventilation rate, which increased its I/O ratio. Ozone concentration ranges paralleled nitrogen dioxide ranges in the two hospitals (I/O average ratios, 0.33 and 0.26 for Hospital A and B, respectively). The lower I/O ratios for ozone than for NO_2 indicated that ozone was not affected by traffic flow and weather. This result is consistent with that of the correlation analysis in Table 1.

Table 2 shows indoor air levels of NO_2 and O_3 reported in several countries. The NO_2 levels in our two hospitals were 54.14 and 32.69 ppb, respectively, which is higher than that detected in bedrooms in Gallelli, Italy (13.2 ppb) and Spengler, USA (27.2 ppb) and lower than that detected in ice rinks in Pennanen, Finland (176.5 ppb) (Gallelli et al. 2002; Pennanen et al. 1998; Spengler et al. 1994). Shiau (1987) found similar levels of NO_2 in ordinary living rooms in Taiwan (50 ppb). Taiwan does not yet have a regulatory standard for indoor NO_2 concentration. However, NO_2 level in our two hospitals was lower than 250 ppb (the standard of indoor air quality set by the US EPA). The O_3 level in our two hospitals (15.0 and 9.7 ppb) was lower than in ordinary living rooms (50 ppb) (Jakobi and Farian 1997) and office buildings (45 ppb) (Weschler and Shields 1994). The O_3 level was also lower in our hospitals than the standard value (30 ppb) set by the Taiwan EPA. Although the air quality of our two hospitals varied as a result of such factors as outdoor pollution, ventilation rate, etc., overall, both the NO_2 and O_3 levels were within the limits set by standard regulations. Also, these factors have not been shown to pose health threats to

Table 2 Nitrogen dioxide and ozone levels in indoor air

Compounds	Country	Sampling site	Concentration (ppb)	Reference
NO_2	Italy	Bedroom	13.2	Gallelli et al. (2002)
	USA	Bedroom	27.2	Spengler et al. (1994)
	Finland	Ice rink	176.5	Pennanen et al. (1998)
	Taiwan	Living room	56.1	Shiau (1987)
	Taiwan	Hospital A	54.1	This study
	Taiwan	Hospital B	32.1	This study
O_3	Germany	Living room	50.0	Jakobi and Farian (1997)
	USA	Office	45.0	Weschler and Shields (1994)
	Taiwan	Hospital A	15.0	This study
	Taiwan	Hospital B	9.7	This study

patients in the hospitals. Nonetheless, indoor air quality of hospitals should be continually monitored and individual exposure evaluated to ensure public health. Good ventilation in hospital should be encouraged to maintain indoor air quality. Up to now, no regulatory standard for indoor NO_2 level has been set in Taiwan because so few studies have been done. The results will provide a local data to help revise the indoor air quality regulations issued by the relative agencies. As our study was conducted over a period of one month only, the data we collected may be limited in terms of temporal generality, and for a further project, we need to cover a longer time, in order to collect adequate information and data to make to accurately evaluate indoor air quality and health risk in hospital.

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