Current asthma and respiratory symptoms among pupils in Shanghai schools, in relation to indoor mould growth and exposure to traffic exhausts in the schools

Y.-H. Mi[a], D. Norbäck[a,*] J. Tao[b], Y.-L. Mi[b], M. Ferm[c]

[a]*Department of Occupational and Environmental Medicine, University Hospital and Uppsala University, Uppsala, Sweden;* [b]*Jiao Tong University, Shanghai and Shanghai Teachers University, Shanghai, China;* [c]*IVL Swedish Environmental Reseach Institute, SE-402 58 Gothenburg, Sweden*

ABSTRACT
We measured the temperature, relative air humidity (RH), carbon dioxide (CO_2), ozone (O_3), nitrogen dioxide (NO_2), and formaldehyde levels in 30 classrooms in 10 schools in Shanghai. The pupils received a questionnaire; 1414 participated (99%). The temperature was 13–21°C, and RH was 36–82%. The 1000 ppm CO_2 level was exceeded in 45% of the classrooms. Indoor formaldehyde was 3–20 $\mu g/m^3$. The concentration of O_3 was low, both indoors (<2–12 $\mu g/m^3$), and outdoors (17–25 $\mu g/m^3$). NO_2 was high, both indoors (33–85 $\mu g/m^3$) and outdoors (45–80 $\mu g/m^3$). Building dampness was associated with an increase of current wheeze ($p < 0.05$), daytime breathlessness ($p < 0.01$), and asthma attacks ($p < 0.05$) (OR = 2.1–3.7). Indoor NO_2 was associated with more daytime breathlessness ($p < 0.05$), asthma attacks ($p < 0.01$) and asthma medication ($p < 0.01$). Indoor CO_2 and O_3 was associated with less daytime attacks of breathlessness ($p < 0.05$). The study indicates that airway symptoms among pupils are influenced by indoor mould growth and outdoor air pollution from traffic exhausts.

INDEX TERMS

Asthma; Carbon dioxide; Moulds; Nitrogen dioxide; Schools

INTRODUCTION
There are a few studies on the health significance of exposures in the school environment, with respect to asthma and allergy in pupils. Recent studies have shown that the classroom concentration of formaldehyde (Smedje *et al*., 1997; Smedje and Norbäck, 2001), respirable dust (Smedje *et al*., 1997), total amount of dust in the classroom (Smedje and Norbäck, 2001), and cat allergen (Smedje *et al*., 1997b; Smedje and Norbäck, 2001), can be associated with an increase of asthma or asthmatic symptoms in pupils. There are few international publications on the school environment from Asia or China (Zhao, 1991; Lee *et al*., 2000; Su *et al*., 2001). The indoor environment in Asian countries may differ from that in northern Europe. It can be expected that the influence of outdoor air pollutants on the indoor environment is stronger because of a high air exchange rate from natural ventilation.

The first aim was to measure indoor climate and CO_2, NO_2, O_3 and formaldehyde in classrooms of junior high schools in Shanghai. The second aim was to study associations between these compounds and current asthma, current respiratory symptoms and reports on pollen and furry pet allergy among the pupils.

[*] Corresponding author. E-mail: dan.norback@medsci.uu.se

MATERIAL AND METHODS

In China, children go through 6 years of primary school, followed by a 3 years of junior high school. Shanghai is the largest city in China with approximately 16 million inhabitants, situated at the coast in mid-China. School administrations in two people's communes in Shanghai were contacted. One commune was situated in central Shanghai, with totally 30 primary schools. The other was in the western part of Shanghai near the major river, with totally 24 primary schools. Five schools were randomly selected from each of the two communes. The headmasters were contacted and all schools agreed to participate in the investigation.

Three classes from the 1st form were selected from each of the 10 schools. All pupils in the 30 classes (N = 1435) received a questionnaire in November 2000. It included the core questionnaire from the International Study Group of Asthma and Allergies in Childhood (ISAAC) (ISAAC, 1998). It also contained additional questions from the previous Swedish school study (Smedje *et al*., 1997), and some questions from the European Community Respiratory Health Survey (ECRHS) (Janson *et al*., 2001). The questions were translated from Swedish or English to Chinese by one person, and back-translated by another person. The questionnaires were distributed by the teachers, and were answered by the pupils the same day. This publication deals with respiratory symptoms from the ECRHS questionnaire.

Building Inspection and Microbial Measurements

Inspections and measurements were performed in November to December 2000, in the home-classrooms (N = 30) where the pupils spend most of the time. Signs of visible mould growth were noted. Room temperature, relative air humidity, and CO_2 concentrations were recorded by Q-track, a direct reading instrument with an in-built data logger (TSI Incorporated, ST Paul, Minnesota, USA). The instrument was calibrated by the local importer in Uppsala, prior to the measurements in China. These indoor climate measurements were performed during 1 h, when the pupils were eating lunch in their classroom. The number of persons in the classroom was noted, as well as the number of open windows and open doors. The personal outdoor air supply was estimated from the indoor CO_2 concentration. Formaldehyde was sampled by pumped air sampling on glass fibre filters impregnated with 2.4-dinitro-phenylhydrazine, with a sampling rate of 0.2 l/min for 4 h.

Indoor and outdoor NO_2 and O_3 were sampled by diffusion sampling during 7 days, with one sampler in each classroom, and one sampler outside each school. A 'badge type' sampler fully based on the theory for diffusion sampling was used (Ferm and Svanberg, 1998). With this type of sampler, the theoretical sampling rate can be used to calculate the pollutant concentrations, and active movement of air and other artefacts are minimized. The lower detection limits for 1 week sampling is 0.4 µg NO_2 per m^3 and 4 µg O_3 per m^3. The precision is ±5% for both samplers. The samplers were prepared and analysed at an accredited laboratory.

Statistical Methods

Statistical analysis was performed by multiple logistic regression analysis. Initially, a simple model was used. This model (I) contained four explanatory variables: age, gender, smoking and each exposure variable introduced separately. Finally, a complex model with eight explanatory variables: age, gender, current tobacco smoking, building dampness in the school, indoor CO_2, indoor formaldehyde, indoor NO_2 and indoor CO_2 was used. For formaldehyde,

NO_2 and O_3, the OR was calculated for an increase of the indoor concentration by 10 μg/m^3. For CO_2, the ORs were calculated for an increase of 100 ppm CO_2.

RESULTS

The mean age of the buildings was 33 years (range 3–65 years). None had a mechanical ventilation system or air-conditioning or any heating system. All were concrete buildings with openable windows. One classroom (3%) had a wooden floor. The other classrooms (97%) did not have any floor covering and the floor consisted of unpainted concrete. One school had signs of building dampness, with water leakage and visible moulds. All schools had daily floor cleaning and daily desk cleaning. Measurement data are presented in Table 1.

Table 1 Average indoor and outdoor climate and air pollutants in 30 classrooms in Shanghai

	M(SD)	Min–Max value
Outdoor parameters (N = 30)		
Number of pupils in the room	48(5)	36–56
Room temperature (°C)	17.4(1.8)	13.4–20.7
Relative air humidity (%)	56(12)	36–82
Air exchange rate (per hour)	9.1(5.8)	2.9–29.4
Personal outdoor air supply flow rate (l/s)	8.8(4.6)	2.6–21.7
Carbon dioxide (ppm)	1060(370)	530–1910
Formaldehyde (μg/m^3)	9.4(6.9)	3–20
NO_2 (μg/m^3)	55(13)	33–86
O_3 (μg/m^3)	5.3(2.8)	1.1–7.0
Outdoor parameters (N = 10)		
Daily mean temperature (°C)[a]	11.1(1.9)	7.9–14.1
Daily mean humidity (%)[a]	69(13)	52–95
Wind velocity (m/s)[a]	8.0(1.5)	5.6–10.8
NO_2 (μg/m^3)	63(13)	47–83
O_3 (μg/m^3)	20.9(3.6)	17–28

M(SD) = arithmetic mean with standard deviation.
[a]Data obtained from the meteorological station, for the measurement days.

As a next step, the correlation between different indoor and outdoor parameters was investigated. The room temperature in the classrooms was strongly related to the outdoor temperature ($r = 0.68$; $p < 0.001$). The indoor relative humidity (RH) was increased at higher indoor levels of CO_2 ($r = 0.56$; $p < 0.01$), at higher relative air humidity outdoors ($r = 0.92$; $p < 0.001$). Indoor formaldehyde was increased at higher outdoor air humidity ($r = 0.39$; $p < 0.05$), but not related to any other indoor exposure. Indoor NO_2 was higher at higher indoor concentration of O_3 ($r = 0.41$; $p < 0.05$), but not related to any other measured indoor exposure. Indoor O_3 was not correlated with any other indoor exposure, except NO_2. There were no significant associations between wind velocity and any of the measured indoor parameters.

In total 1414 pupils answered the questionnaire (99%). The mean age was 13.0 years, 50% were girls and 0.6% were smokers. When asking about airway symptoms during the latest 12 months, daytime attacks of breathlessness was common (23.0%), particularly breathlessness during exercise (20.9%), while night-time attacks of breathlessness was uncommon (2.6%), and wheeze was uncommon (3.1%). The cumulative incidence of doctor's diagnosed asthma was 8.9% in the total material. Girls reported less doctor diagnosed asthma. Speaking specifically of asthma, 2.4% had current asthma medication, 2.3% had an asthma attack in the last 12 months, and 3.1% had current asthma (defined as either asthma attacks or asthma medication). Pollen allergy was reported by 4.4%, furry pet allergy to cats or dogs was uncommon (1.6%) and totally 5.6% reported either pollen or pet allergy.

The association between symptoms, and exposures was investigated, by two different statistical models (Table 2). In most cases, the results were similar with both regression models, when comparing ORs.

Table 2 Relationship between indoor exposure, airway symptoms and current asthma

	Current wheeze OR (95% CI)	Daytime breathlessness OR (95% CI)	Current asthma OR (95% CI)
Building dampness	Model I 2.12(0.96–4.67)	1.14(0.76–1.72)	1.75(0.76–4.01)
	Model II 3.65(1.05–12.7)*	2.51(1.46–4.32)**	3.27(0.91–11.7)
CO_2 concentration	Model I 1.06(0.95–1.17)	0.96(0.92–1.00)*	1.18(1.06–1.32)**
	Model II 0.96(0.83–1.12)	0.94(0.89–1.00)*	1.10(0.94–1.29)
Formaldehyde	Model I 1.04(0.59–1.82)	1.09(0.86–1.38)	1.30(0.74–2.29)
	Model II 0.84(0.46–1.53)	1.12(0.87–1.45)	0.95(0.47–1.92)
NO_2 concentration	Model I 1.24(0.97–1.59)	0.97(0.88–1.08)	1.50(1.16–1.92)**
	Model II 1.50(0.99–2.28)	1.23(1.05–1.44)*	1.52(1.02–2.27)*
O_3 concentration	Model I 2.36(0.51–10.9)	0.42(0.23–0.76)**	2.42(0.52–11.3)
	Model II 0.27(0.03–2.86)	0.17(0.07–0.42)***	0.10(0.01–1.26)

* $p < 0.05$; ** $p < 0.01$; ***$p < 0.001$.
Model I: adjustment for age, gender and smoking only.
Model II: adjustment for age, gender, smoking and visible indoor moulds, formaldehyde, CO_2, NO_2, O_3, kept at the same time in the model.

Visible indoor mould growth was associated with an increase of current wheeze, daytime breathlessness, and asthma attacks. Increased indoor CO_2 was associated with a decrease of daytime attacks of breathlessness, but an increase of asthma attacks and asthma medication in model I. Increased indoor NO_2 was associated with more daytime breathlessness, asthma attacks, and increased asthma medication. Indoor O_3 was negatively associated with daytime breathlessness, both in models I and II. There was no association between indoor formaldehyde concentrations and any type of health effects. Finally, there was no significant association between reports on pollen allergy or furry pet allergy, and building dampness or any of the measured indoor exposures. Moreover, there were no association between night-time breathlessness and any exposure.

DISCUSSION

Shanghai is the wealthiest part of China, situated in a subtropical coastal area. The outdoor daily mean temperature during the sampling period (November–December) was 8–17°C, and the outdoor relative air humidity was 40–97% RH. Somewhat higher temperatures and humidity levels were measured in the classrooms. All school buildings in our study had a simple wall construction, made of bricks or concrete. Moreover, the buildings contained little organic building materials, and none had a heating system, air conditioning or any mechanical ventilation. The air exchange rate was good in the classrooms (4.7–26.2 turnovers per hour), due to frequent window opening. Because of high population density, the recommended ventilation standard of 1000 ppm CO_2 was exceeded in 45% of the classrooms, and peak exposure up to 6000 ppm was measured. Reports on current asthma and airway symptoms were relatively common among secondary pupils in Shanghai, China, particularly daytime breathlessness during exercise. Reports on pollen and furry pet allergy were uncommon, as compared to data from school children in western countries (e.g. Smedje *et al*., 1997). Visible mould growth was observed in one of the 10 schools (10%), and was related to an increase of current wheeze, daytime attacks of breathlessness and asthma attacks (OR = 2.1–3.7). This is in agreement with conclusions from two previous reviews on the health effects of building dampness, suggesting a twofold increase of airway symptoms in buildings with signs of dampness and microbial growth (Bornehag *et al*., 2001). The relationship between building dampness and airway symptoms in our study was strengthened when controlling for the effect of other indoor factors, including the CO_2 concentration.

The indoor exposure to NO_2 was relatively high in the classrooms as compared to current air quality guidelines (WHO, 2000), and the outdoor levels of NO_2 exceeded the recommended annual mean value of 40 μg/m^3 in all schools. Moreover, we found an association between the classroom concentration of NO_2 and daytime breathlessness, current asthma and asthma medication. There are few other studies available on the association between NO_2 in schools and respiratory symptoms among pupils. The Guideline for Air quality by WHO has reviewed the toxicological and epidemiological literature on indoor and outdoor NO_2 exposure (WHO, 2000). At higher levels of NO_2, about 940 μg/m^3, the susceptibility to bacterial and viral infections in the lung is increased. In homes with cooking gas, children 5–12 years old are estimated to have a 20% increased risk for respiratory symptoms and disease for each increase of 28 μg/m^3 NO_2 (2 week average). The epidemiological literature on NO_2, as reviewed by WHO (WHO; 2000) suggests respiratory effects in children at annual average NO_2 concentrations in the range 50–75 μg/m^3 or higher, similar levels as the outdoor levels measured in our school study in Shanghai.

In contrast, the indoor levels of O_3 and formaldehyde were low as compared to the air quality guidelines of 120 and 100 μg/m^3, respectively (WHO, 1987; WHO, 2000). The indoor mean level of formaldehyde was 9 μg/m^3, similar to the outdoor level in Shanghai of 7–9 μg/m^3 measured during winter conditions (Norbäck, personal communication), and similar to the mean formaldehyde concentration (6 μg/m^3) measured in Swedish schools (Smedje *et al*., 1997b). We found a negative association between indoor O_3 and daytime attacks of breathlessness. Our negative association is difficult to explain, but could possibly be due to consumption of ozone with formation of other compounds with more irritative properties. The associations between CO_2 levels in the schools and respiratory symptoms were not consistent, with both positive and negative associations. This could be due to the fact that increased ventilation by opening of windows may decrease the exposure from indoor sources (e.g. indoor moulds), but increase the exposure to outdoor air pollution, e.g. NO_2 from traffic exhausts.

CONCLUSION AND IMPLICATIONS

Current asthma medication and respiratory symptoms among pupils in Shanghai schools can be influenced by the school environment. Improvements could include avoiding building up of indoor mould growth, and reduction of indoor exposure to traffic exhausts.

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