Particulate matters in school environments: assessing the effectiveness of a low allergen school

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ABSTRACT
School is a major indoor environment in which children may be exposed to high levels of pollutants. However, little research has been done to assess their exposure to particulate matter in classrooms. This study was designed to monitor the levels of PM_{10} and ultrafine particles in school environments and to assess whether a "low allergen" school has lower levels of particulate matters in the air. The "low allergen" primary school and three other primary schools chosen were all located within the Perth metropolitan area. Concentrations of PM_{10} and ultrafine particles were monitored in the four schools during 2002. No significant differences in PM_{10} and ultrafine particle concentrations between the schools were found. There was significant difference in PM_{10} between school term time and school holidays. Classroom ultrafine particles were significantly correlated with outside ultrafine particles. But in some cases classroom sources can put the children at a greater risk of exposure to ultrafine particles in schools.

Keywords: School environments, PM $_{10}$, Ultrafine particles

INTRODUCTION

Many epidemiological studies (Schwartz et al. 1993; Sheppard et al. 1999; Laden et al. 2000; Atkinson et al. 2001; von Klot et al. 2002) have confirmed that exposure to particulate matters (PM) is associated with a variety of adverse health effects and the link between particle matter exposure and health is generally regarded as causal and a non-threshold linear relationship (Martuzzi et al. 2003).

Apart from the home, school is a major indoor environment for school age children (Smedje et al. 1997), since they spend about one third of their time in school, mostly in classrooms. It has been reported (Janssen et al. 1997) that exposure by children to particulate matter mainly come from ambient and domestic environments as well as school environments. Therefore, they could be at significant health risk owing to their exposure to PM in classrooms. Unlike the domestic environment, little investigation has been conducted within the school environment, although a few reports available examined indoor air quality in classrooms (Almqvist et al. 1999; Banks 1999; Ahman et al. 2000; Lee and Chang 2000; Etzel 2001; Amr et al. 2003; Leickly 2003).

In Australia, limited information regarding indoor air quality in schools has been identified (Wardrope et al. 2001). The present study aims to determine the levels of PM_{10} (less than 10 micrometer in diameter) and ultrafine particles (0.02 to greater than 1 micrometer in diameter) in schools and to assess whether a "low allergen" school has lower levels of particulate matters compared with other schools.

METHODS

Study schools

The "low allergen" primary school (Endeavour) and three 'normal' primary schools (Singleton, Koorana and Port Kennedy) chosen for this study were all located within the Perth metropolitan area. The "low allergen" school, open in 2000, was designed to be "allergy free" by undertaking several measures to eliminate dust and hazardous chemicals. Measures to improve indoor air quality included: vinyl flooring, ducted vacuum system, overhead radiant

heating, no blackboard and sloped window sills**.** The other three schools were in the vicinity of the "low allergen" school (target school), as well as similar in both age and size, but no special measures to eliminate dust and hazardous chemicals were taken when the schools were initially built. Ambient particle matters (PM_{10} and $PM_{2.5}$) have been regularly recorded in three air-monitoring stations in the Perth Metropolitan area by the Department of Environmental Protection (DEP). The 2002 data showed that ambient PM_{10} was less than 20 $\mu g/m^3$ (Department of Environmental Protection 2003).

Sampling and monitoring methods
Four visits (summer term, winter term, spring holiday and winter holiday) were made at each school in 2002.

PM $_{10}$
During the summer term, particulate matter PM_{10} was measured in each classroom of the target school and several randomly selected classrooms in the control schools. During the other visits, 6 classrooms were randomly selected from each of the studied schools. No entrance assess was available to Endeavour's classrooms during the autumn holiday and only two selected Port Kennedy classrooms were available for measurement during the winter holiday period. PM_{10} was monitored continuously by a DustTrak aerosol monitor for about two hours at the height of 0.6 m in the classrooms. The average concentration of PM_{10} was reported.

Ultrafine particles
During the summer term, a pilot study of ultrafine particles were conducted in Koorana Primary School, where most of its classrooms were monitored. For other visits, 20% of classrooms stratified by teaching blocks were randomly selected for measurement. The concentration of ultrafine particles were measured utilizing P-TRAK ultrafine Particle Counter (Model 8525) (with a range of 0.02 to greater than 1 micrometer) in each classroom three times: 9:00 am, 11:00 am and 2.00 pm at the same height as that for PM_{10}. Outside ultrafine particles was monitored on the playgrounds of the schools at the height of 1.6 m, in order to minimize wind influence. A 10 second average point value was recorded in the monitor and the concentration was expressed in unit of particles/cm^3.

Statistics methods
PM_{10} and ultrafine particle concentrations were positively skewed. Therefore, geometric means (GM) were calculated after applying logarithmic transformation. Analysis of variance, independent samples T-test and bivariate correlation were used to explore the differences and associations. All statistical analyses were performed using the SPSS package Version 10.0.

RESULTS
Particle Matter (PM_{10}) in classrooms
Table 1 displays concentrations of PM_{10} in the four schools. The differences among the schools and between summer term and winter term in terms of PM_{10} were not significant. The target school did not have a lower concentration of PM_{10}, compared with the three control schools. During the school holiday, the concentration of PM_{10} in the classrooms appeared to be at a reasonably low level, relative to the school term. Figure 1 shows that the difference between the school term and the school holiday was significant in each of the four-study schools. Variations of PM_{10} in one classroom over a normal school day in Singleton were observed on 27th February 2002; results of which are plotted against time in Figure 2. The

levels of PM_{10} were relatively low at recesses and lunchtimes, when the children left the classroom. It is also evident that writing class with less activities had a lower level of PM_{10}. With respect to the US EPA recommendation of less than 50 $\mu g/m^3$ for good air quality (Cohen 1999), 8% (9/113) two-hour average of PM_{10} concentrations in the classrooms of the four schools were above the standard.

Table 1 Geometric means (GM) and 95% confidence intervals (95% CI) of PM_{10} concentration ($\mu g/m^3$) in the four study schools

	Endeavour			Port Kennedy			Singleton			Koorana		
	N	GM	95% CI	N	GM	95% CI	N	GM	95% CI	N	GM	95% CI
Summer Term	14	28.8	19.4-42.9	15	34.0	28.3-40.8	14	28.2	21.2-37.4	16	24.9	19.4-31.9
Winter term	6	24.5	19.2-31.1	6	23.2	15.8-34.3	6	27.1	18.8-39.1	6	21.8	15.4-30.9
Autumn holiday	--	--	--	6	6.0	3.0-12.3	6	13.1	9.1-18.7	6	5.6	4.5-6.8
Winter holiday	6	9.2	6.7-12.5	2	16.5	11.2-24.2	6	13.3	10.7-16.1	6	13.1	11.7-15.0

Figure 1 Geometric means of PM_{10} concentration ($\mu g/m^3$) during school terms and school holidays in the classrooms

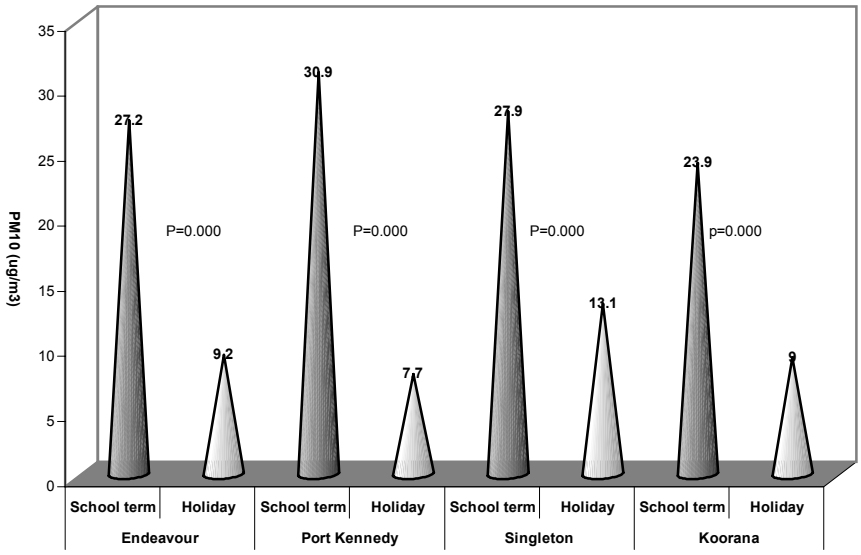
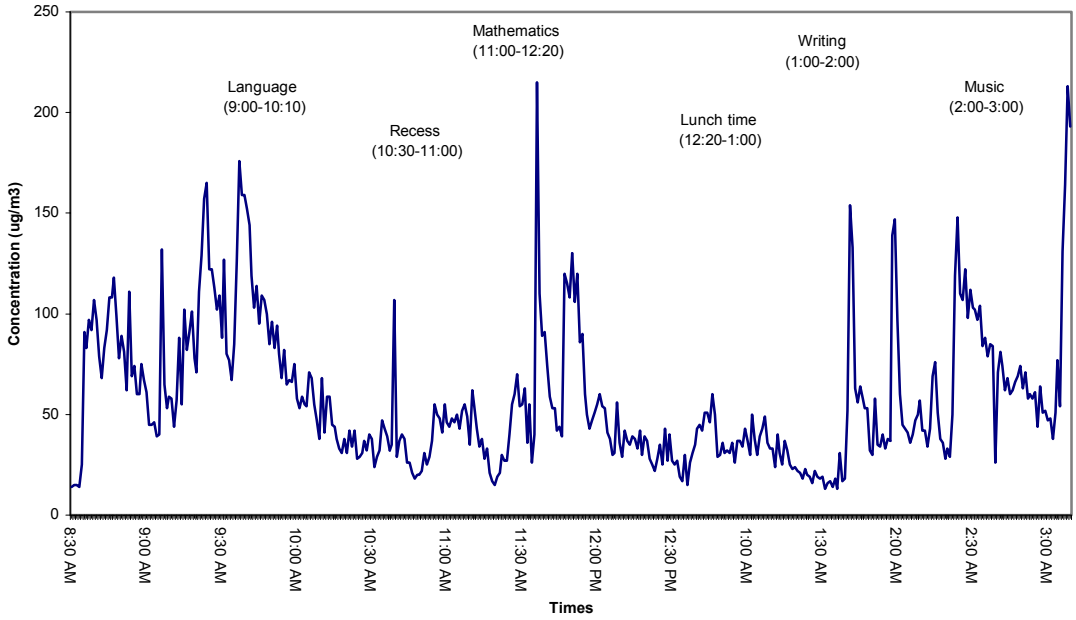


Figure 2 PM_{10} variation over a normal school day



Ultrafine particles in classrooms and outdoor

A total of 133 measurements of ultrafine particles were collected from the classrooms of the four schools and at the same time outdoor ultrafine particle measurements were taken in the school gardens. The association between classroom and outside readings was positive and significant ($r=0.79$; $p<0.001$).

Table 2 Geometric means (GM) and 95% confidence intervals (95% CI) of ultrafine particle concentration (particles/cm^3) in the four study schools

	Endeavour				Port Kennedy			
	N	GM	95% CI	Outdoor GM	N	GM	95% CI	Outdoor GM
Autumn holiday	9	2295	1734-3037	1896	24	4253	3355-5391	6039
Winter holiday	9	830	472-1458	382	8	871	406-1869	586
Winter term	9	6773	4854-9452	6326	9	5991	5244-6844	4361
	Koorana				Singleton			
Summer term	28	4492	3428-5911	5099	--	--	--	--
Autumn holiday	14	4323	3086-6057	5876	9	3144	2084-4742	4151
Winter holiday	9	8860	6946-11303	10082	9	413	277-616	537
Winter term	15	3459	2434-4917	2373	9	6212	2677-14416	4341

Table 2 shows that there were substantial differences in ultrafine particles concentration among the schools and across the seasons. The outdoor ultrafine particles concentration also

varied considerably. Moreover, the target school did not achieve a significantly lower concentration of ultrafine particles.

When outdoor ultrafine particles exceeded 5000 particles/cm^3 (≈ geometric mean), 67.2% of the classrooms had a lower concentration of ultrafine particles than outside, while those with outdoor ultrafine particles <5000 particles/cm^3, 73.8% of the classrooms had a higher concentration of ultrafine particles than outside. However, two significant differences between classrooms and outdoor were found at 11:00 am (morning tea) during winter school term in the junior area of Koorana and Singleton. The outdoor ultrafine particles concentrations were less than 5000 particles/cm^3 at that time but the classroom ultrafine particle concentrations were 26500 and 25300 particles/cm^3, suggesting some other source(s) of pollutants inside the classroom for the elevated ultrafine particle levels.

DISCUSSION

The target school did not attain significantly lower levels of PM_{10} and ultrafine particles. This suggests that removal of blackboards and standard dust prevention strategies could not effectively decrease exposure to particulate matters in the classroom.

Our results showed that PM_{10} was higher during school term than in school holidays and it was also higher during class time than recess and lunchtime when children left the classrooms, suggesting that activities within the classroom environment can account for the elevated levels of PM_{10}. This finding is consistent with the literature (Thatcher and Layton 1995; Wardrope, Rutherford et al. 2001).

In this study, the PM_{10} levels in classrooms were compared with the ambient data collected by the Department of Environmental Protection. During school term, indoor PM_{10} concentration in classrooms was significantly higher than outdoor.

According to the standard set by US EPA(Cohen 1999), most classrooms in the four schools can be considered to have a good air quality in term of PM_{10} But in view of 'nonthreshold linear relationship of exposure to particulate matter and its adverse health effects', more efforts need to be made to reduce the level of PM_{10}.

Recently, ultrafine particles are suspected of provoking alveolar inflammation and subsequently causing an exacerbation in pre-existing cardiopulmonary diseases (Peters et al. 1997; Penttinen et al. 2001; Pekkanen 2003) . There are two methods to measure air-borne ultrafine particles: mass measurement and number count. The former method can be strongly influenced by mechanically produced, soil-derived particles, which may not be associated with adverse health effects (Pekkanen 2003). Thus the number count method was used in this study.

Our results confirmed the strong positive association between classroom and outdoor ultrafine particle levels. Although outdoor ultrafine particle concentration could contribute to indoor $PM_{0.1}$, the significantly elevated levels of ultrafine particles inside the classrooms suggested alternative sources of ultrafine particles within the school environment.

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