

Indoor environmental quality in a 'low allergen' school and three standard primary schools in Western Australia

Abstract To investigate indoor environmental quality in classrooms, assessments were undertaken in a 'low allergen' school and three standard primary schools in Western Australia. Dust allergens, air pollutants and physical parameters were monitored in the four schools at four times (summer school term, autumn holiday, winter school term and winter holiday) in 2002. The levels of particulate matter (PM₁₀) and volatile organic compounds were similar between the four primary schools. Although slightly decreased levels of dust-mite and cat allergens were observed in the 'low allergen' school, the reductions were not statistically significant and the allergen levels in all schools were much lower than the recommended sensitizing thresholds. However, significantly lower levels of relative humidity and formaldehyde level during summer-term were recorded in the 'low allergen' school. In conclusion, the evidence here suggests that the 'low allergen' school did not significantly improve the indoor environmental quality in classrooms.

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Practical Implications

School is an important environment for children in terms of exposure to pollutants and allergens. By assessing the levels of key pollutants and allergens in a low allergen school and three standard primary schools in Western Australia, this study provides useful information for implementation of healthy building design that can improve the indoor environment in schools.

Introduction

School provides a major indoor environment for children apart from their home. Children may spend up to 10 h per day at school, and at least 1100 h per year (Leickly, 2003), so that the indoor air quality in school can have a substantial impact on the health of children. It has been suggested that exposure to air pollutants and allergens at school was associated with an increase in prevalence of respiratory symptoms and asthma (Smedje et al., 1997). Therefore, reducing exposure to pollutants and allergens at school and improving indoor environmental quality is an important public health issue.

Several pollutants have been reported to exist in classrooms, such as formaldehyde (HCHO), volatile organic compounds (VOCs) and particulate matter (PM₁₀), with levels that can be harmful to the health of children (Carrer et al., 2002; Daisey et al., 2003). Pet allergens found in classrooms were most likely transferred from home (Rutherford, 2000). High levels of dust-mite allergens (Der P1) were also reported (Amr et al., 2003). Despite the importance of good indoor air quality to children, relatively few studies have investigated indoor environmental quality in schools.

A 'low allergen' primary school was set up in Perth, the capital of Western Australia, and opened in

February 2000, with the expectation of improving indoor environmental quality. This study investigates as to whether this new 'low allergen' school can significantly improve the indoor environmental quality in classrooms. Assessments were undertaken in the 'low allergen' school and three standard primary schools located in its vicinity, by monitoring the indoor Der P1, cat allergen (Fel D1), PM₁₀, HCHO, VOCs and physical parameters (temperature and relative humidity) over a 1-year period. The study provided valuable information on indoor concentrations of several key pollutants in school environments.

Methods

Study schools

The 'low allergen' school was designed to be 'allergy free'. Several measures were implemented to eliminate dust and hazardous chemicals. These included avoiding dust accumulation (construction of storage cupboards to the ceiling and sloped window sills), improving the indoor-outdoor air exchange through large ventilation vents, avoiding soft furnishings and carpet in classrooms (vinyl flooring) and replacing ceiling insulation that can generate dust particles with sealed insulation products along with paints, adhesives and sheathed particle boards that have lower emissions of VOCs. In addition, a radiant heating system was installed instead of a gas heating system. A central vacuum cleaning system was also installed to prevent the release of dust back into the air. White boards rather than black boards were used in the classrooms.

Three other government primary schools were chosen for comparison. They are in the vicinity of the 'low allergen' school, of a similar age and size, and use natural ventilation for air exchange. Routine (everyday) cleaning practices are being performed in both the 'low allergen' and standard schools. All four schools were set up in the late of 1990s, located in the Rockingham area within metropolitan Perth and situated along the southwest coast of Australia. In the 'low allergen' school, there were 15 classrooms and for the standard schools the number of classrooms ranged from 17 to 27.

Sampling and assessment

Four assessments (summer term, winter term, spring holiday, and winter holiday) were made at each school over a 1-year period. For the initial summer term assessment, a thorough investigation was undertaken on all classrooms in the 'low allergen' school and most of the classrooms in the standard schools. For the following three sampling times, six classrooms selected randomly from each school were monitored. Samples for air-borne pollutants and physical parameters were collected between 8:00 a.m. and 3:30 p.m. during the

school term, which corresponded to the hours that children were in the classroom. Passive or active samplers were located in the middle part of the classroom at a height of 0.6 m above the ground. Settled dust samples were collected after school from the classroom floor using a hand vacuum for approximately 2 min, covering an area of 1 m². Dust samples were then stored in a freezer before being transported for laboratory analyses. The samples were analyzed for Der P1 and Fel D1 by modified ELISA assay (time-resolved fluorometry). Particulate Matter was measured continuously by a DustTrak aerosol monitor (TSI Inc., Shoreview, MN, USA) for 2 h in each classroom. HCHO was collected by the passive sampling method described previously (Rumchev et al., 2002a). The sample was analyzed with high-performance liquid chromatography. VOCs were measured by active sampling using charcoal sorbent tubes. The analyses were performed with a Perkin Elmer Autosystem XL gas chromatograph (LabX, Midland, Canada) equipped with a flame ionization detector. Ten common compounds were identified and quantified by comparing the retention times: benzene, toluene, chlorobenzene, *m,p*-xylene, *o*-xylene, ethylbenzene, styrene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, and 1,4-dichlorobenzene. These ten compounds were selected following our previous study (Rumchev et al., 2004). Their amounts were then summed and expressed as total VOCs (TVOCs). Finally, temperature (°C) and relative humidity (%) in the classrooms were measured by Tinytalk II Data Loggers (Gemini Ltd., Chichester, UK) during the sampling time.

Statistics analysis

The concentrations of Der P1, Fel D1, PM₁₀, HCHO and TVOCs appeared to be positively skewed. Consequently, their geometric means (GM) and 95% confidence intervals (CI) were calculated after applying a logarithmic transformation. Analysis-of-variance with *post-hoc* multiple comparisons were conducted to assess the differences between the 'low allergen' and standard schools. For physical parameters, covariance analysis adjusting for outdoor temperature and humidity was used to quantify the temperature and relative humidity levels inside the classrooms. All statistical analyses were performed using the SPSS package Version 11.0 (SPSS Inc., Chicago, IL, USA).

Results

Dust-mite and cat allergens

Dust-mite allergen and Fel D1 were measured from a total of 121 dust samples collected in the four schools. Since there was no apparent seasonal variation, data from the four collection times were pooled together for subsequent analysis. The geometric means of Der P1

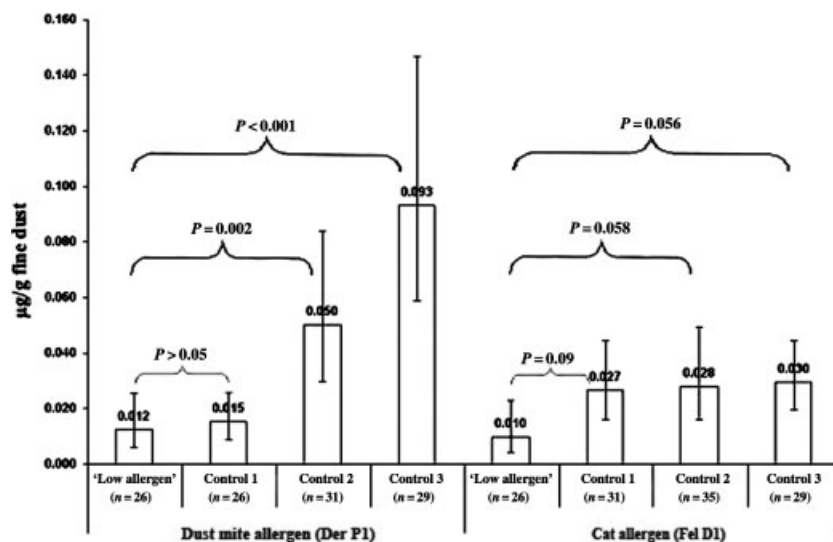


Fig. 1 Geometric means ($\mu\text{g/g}$) and 95% confidence intervals of dust-mite allergen (Der P1) and cat allergen (Fel D1) in the four schools

Table 1 Geometric means (GM) of PM_{10} concentration ($\mu\text{g}/\text{m}^3$) in the four schools

	'Low allergen'			Control 1			Control 2			Control 3		
	N	GM	Range	N	GM	Range	N	GM	Range	N	GM	Range
Summer term	14	28.8	7–100	15	34.0	21–59	14	28.2	14–98	16	24.9	13–51
Winter term	6	24.5	18–32	6	23.2	14–42	6	27.1	18–40	6	21.8	14–35
Autumn holiday	—	—	—	6	6.0	2–15	6	13.1	8–18	6	5.6	4–7
Winter holiday	6	9.2	6–12	2	16.5	16–17	6	13.3	10–17	6	13.1	11–15

and Fel D1 and associated 95% CIs are shown in Figure 1. The *F*-test from analysis-of-variance showed overall significant differences in Der P1 ($P < 0.001$) and Fel D1 ($P < 0.05$) among the four schools, with the 'low allergen' school having the lowest levels. However, *post-hoc* multiple comparisons (Figure 1) found some of the differences between the 'low allergen' school and each of the standard schools were not significant individually. All observed levels of allergens were much lower than the recommended sensitizing thresholds of $2 \mu\text{g/g}$ for Der P1 and $8 \mu\text{g/g}$ for Fel D1 (Leickly, 2003). The highest level was $1.07 \mu\text{g/g}$ for Der P1 and $1.27 \mu\text{g/g}$ for Fel D1.

Particulate matter

About 11% of samples monitored during school term when classes were occupied had levels of PM_{10} exceeding $50 \mu\text{g}/\text{m}^3$. Table 1 displays concentrations of PM_{10} at four monitoring periods in the four schools. The differences among the schools were not significant. During the school holiday, the concentration of PM_{10} in the classrooms appeared to be at a reasonably low level relative to those recorded in the school term time.

Variations of PM_{10} in one standard school classroom over a normal school day on 27 February 2002 are plotted against time in Figure 2. The levels of PM_{10} were relatively low at recess and lunch times when students left the classroom. A lower level of PM_{10} was also observed during the writing class with less activity. However, children can be exposed to $> 100 \mu\text{g}/\text{m}^3$ of PM_{10} at certain class periods.

With respect to the US Environmental Protection Agency recommendation of $< 50 \mu\text{g}/\text{m}^3$ for good air quality (for 24 h, Cohen, 1999), only nine (8%) of the 113 samples of 2-h average PM_{10} concentrations in the classrooms of the four schools exceeded the standard.

Formaldehyde

A total of 141 HCHO samples were collected over the study period. The GM of HCHO and corresponding 95% CI are presented in Figure 3. Differences in HCHO levels between the schools were significant ($P < 0.001$) during the summer school term, with the 'low allergen' school recording significantly lower levels than two standard schools (control 2 and control 3) and marginal significantly lower than the other

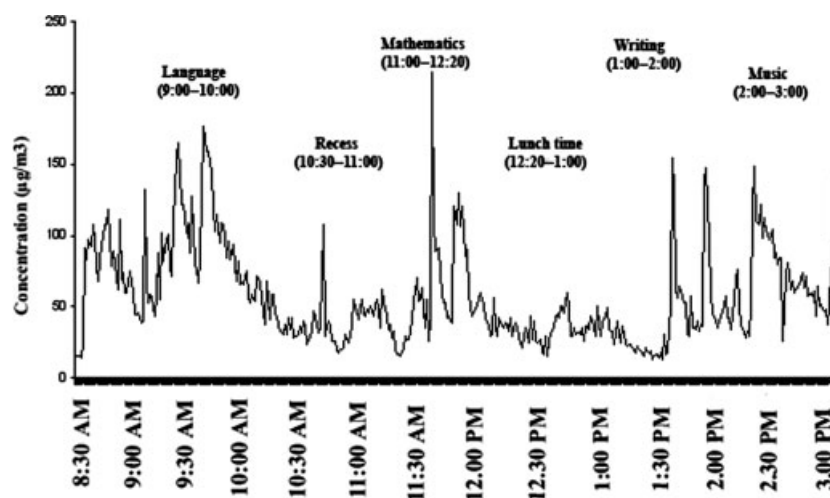


Fig. 2 PM₁₀ variations over a normal school day in control 2 school

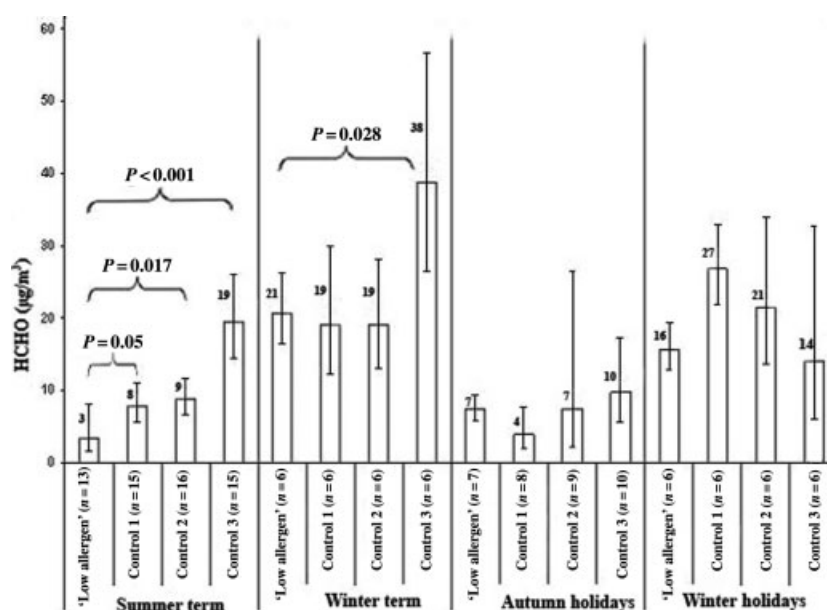


Fig. 3 Geometric means ($\mu\text{g}/\text{m}^3$) and 95% confidence intervals of HCHO in the four schools*. *Statistical analysis: ANOVA with *post-hoc* multiple comparisons

standard school (control 1). Although the 'low allergen' school had a significantly lower level of HCHO compared with control 3 during the winter term, the differences with the other standard schools were not significant. Similarly, no significant differences were detected among the four schools during the holidays. Overall, higher levels of HCHO were recorded in the winter term than summer term and this trend was consistent in all four schools.

Volatile organic compounds

Ninety-eight samples were collected from the four schools and measured for VOCs during the monitoring period. No significant difference in levels of VOCs was

found between the 'low allergen' and standard schools. The VOC levels of most samples were either very low or below the detectable limit. Only 13.7% of samples monitored had levels of TVOCs exceeding $10 \mu\text{g}/\text{m}^3$, with a maximum value of $94 \mu\text{g}/\text{m}^3$ in a visual art classroom. The visual art classroom for art classes was used to store drawing and painting products of students.

Temperature and humidity

Indoor temperature and relative humidity were measured in the four schools during summer and winter school terms. The 'low allergen' school had a significantly lower level of relative humidity than control 3

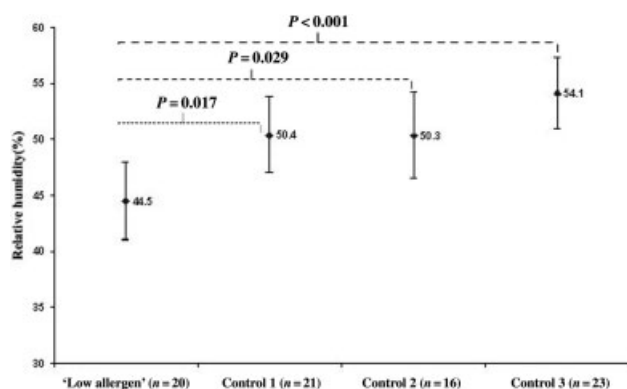
Table 2 Temperature and relative humidity in the four schools

	'Low allergen'		Control 1		Control 2		Control 3	
	N	Mean	N	Mean	N	Mean	N	Mean
Summer								
Relative humidity (%)	14	44.6*	15	50.2	10	45.7	17	53.7
Temperature (°C)	8	24.1	7	26.1	10	24.1	17	24.4
Winter								
Relative humidity (%)	6	46.0**	6	47.2	6	57.5	6	57.9
Temperature (°C)	6	18.6***	6	16.7	6	15.3	6	17.7

*'Low allergen' school vs. Control 3 ($P = 0.033$).

**'Low allergen' school vs. Control 3 and Control 2 ($P < 0.01$).

***'Low allergen' school vs. Control 2 ($P < 0.01$).

**Fig. 4** Adjusted geometric means (%) and 95% confidence intervals of relative humidity in the four schools

during summer, and lower than those of control 2 and control 3 during winter. As shown in Table 2, no significant difference between the 'low allergen' school and control 1 was found in terms of the physical parameters. Since natural ventilation was used in the schools, outside temperature and relative humidity were adjusted in the covariance analysis. No significant difference in classroom temperature was found between schools. However, a significantly lower level of relative humidity in the 'low allergen' school was observed when compared with each standard school separately in Figure 4 (p ranged from 0.029 to <0.001), after adjustment for outdoor humidity and temperature.

Discussion

The 'low allergen' school is the first such school of its kind in Australia. This study thus represents an attempt to assess the effectiveness of the 'allergy free' design. The preliminary evidence suggests that the 'low allergen' school did not significantly improve the indoor environmental quality in classrooms. First, the 'low allergen' school had relatively low levels of dust allergens, which may be attributable to the vinyl floor

coverings in the 'low allergen' school, as evidence has suggested that carpets may be reservoirs for allergens (Foarde and Berry, 2002). Nevertheless, none of the dust samples from the other schools exceeded the Der P1 and Fel D1 sensitizing thresholds. Secondly, the differences in levels of HCHO between the 'low allergen' and standard schools during summer might be partly due to the large vents and ceiling shapes for natural ventilation. However, no significant difference in HCHO levels was found between the schools during winter. Formaldehyde is ubiquitous and can be emitted from a range of building and furnishing and decoration materials, and can vary substantially in most indoor environments (Dudney and Copenhaver, 1984). Furthermore, as ventilation rates or CO₂ concentrations were not measured in the 'low allergen' school and the standard schools in the study, there is thus insufficient evidence to attribute the apparent reduction in HCHO levels to the 'low allergen' school design. Thirdly, no significant differences in levels of PM₁₀ and VOCs were found between the schools. Fourthly, although the 'low allergen' school recorded lower relative humidity, a systematic assessment of physical parameters is needed to confirm the association between reduced humidity and the 'low allergen' school design. Lastly, a survey was also conducted on respiratory symptoms and household characteristics of the students (996 children recruited in the four schools with an average response rate of 62.5%). The student population was drawn from proximate communities around each school. The results indicated that students of the four schools had similar prevalence of respiratory symptoms and asthma (Zhang, 2005). There appears to be little bias in terms of low allergen school pre-selection due to prior allergic conditions.

Although several studies have reported high Der P1 levels exceeding the sensitizing threshold (2 µg/g for Der P1) or even the symptom threshold (10 µg/g for Der P1) in schools (Amr et al., 2003; Tortolero et al., 2002), the findings were generally inconsistent (Ramachandran et al., 2002; Wardrope et al., 2001). In Australia, the warm coastal and humid indoor environments are suitable for mite proliferation (Brown, 1997; Rumchev et al., 2002b), yet exposure to Der P1 in the school environment have not been thoroughly investigated. Our results showed that the levels of Der P1 in schools were very low compared with those of dust samples from domestic environments (Rumchev et al., 2002b). Good cleaning strategy and high occupancy may contribute to such low levels of Der P1 in classrooms.

It has been documented that pet allergens can be transported from homes to classrooms through clothing (Almqvist et al., 1999; Patchett et al., 1997). The level of Fel D1 in classrooms can exceed the threshold value of 8 µg/g (Amr et al., 2003; Godish, 2001). In this study, Fel D1 were detected in most classrooms,

but the levels of Fel D1 were well below the threshold value. Although cat ownership among Australian households is >25% (Rutherford, 2000), it is likely that good cleaning practices implemented in these schools have resulted in low levels of Fel D1s.

Particulate matter is a major indoor air pollutant. In the present study, PM₁₀ was higher during school term than holidays, especially at class times, suggesting that activities within the classroom environment contributed to the elevated levels. This finding is consistent with the literature (Wardrope et al., 2001). The 'low allergen' school did not effectively reduce the levels of PM₁₀. In view of the significant health risk of respiratory diseases for each 10 µg/m³ increase in PM₁₀ (WHO, 2000), further improvements in the 'low allergen' school design are needed in order to control the exposure to PM₁₀.

The samples of HCHO from all schools were below the WHO air quality guideline value (WHO, 2000). However, the average levels of HCHO in classrooms during winter term were similar to the indoor house levels reported by Rumchev et al. (2002a). High exposure to HCHO in domestic environments has been associated with atopy or asthma among Australian children (Grant et al., 1999; Rumchev et al., 2002a). Therefore, controlling HCHO exposure in schools should be given a high priority so as to minimize the potential risks of asthma and atopy.

Volatile organic compounds are common air pollutants in schools (Daisey et al., 2003). For measured VOCs in this study, automobiles may be a significant source. The levels of the VOCs in classrooms were expected to come from outdoor air or from indoor sources in the classrooms. The VOC levels of most samples from all four schools were very low or under the detectable limit. A visual art classroom was identified with a relatively high level of VOCs. The findings suggest that keeping drawing and painting products in a proper storage area separate from the classroom can effectively control this source of VOCs.

In conclusion, the 'low allergen' school design did not significantly improve indoor environmental quality. In order to effectively control and manage the indoor environmental quality, a multi-faceted strategy accounting for construction practice, building maintenance and occupants' activities is needed.

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