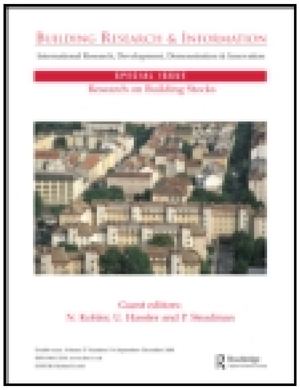

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Indoor environment and pupils' health in primary schools

F. Van Dijken [a] , J. E. M. H. Van Bronswijk [a] & J. Sundell [b]

[a] Department of Architecture, Technische Universiteit Eindhoven, Building and Planning, Postbus 513, NL-5600 MB, Eindhoven, the Netherlands E-mail:

[b] International Centre for Indoor Environment and Energy, Technical University of Denmark, Building 402, DK-2800, Lyngby, Denmark E-mail:

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F. van Dijken[1], J. E. M. H. van Bronswijk[1] and J. Sundell[2]

[1]Technische Universiteit Eindhoven, Department of Architecture, Building and Planning, Postbus 513, NL-5600 MB Eindhoven, the Netherlands
E-mails: fvandijken@hotmail.com and j.e.m.h.v.bronswijk@tue.nl

[2]International Centre for Indoor Environment and Energy, Technical University of Denmark, Building 402, DK-2800 Lyngby, Denmark
E-mail: jas@mek.dtu.dk

Dutch children are legally bound to spend 15% of their time in a school setting. The indoor environment in Dutch primary schools is known to be substandard. However, it is unclear to what extent the health of pupils is affected by the indoor school environment. The paper aims to assess the associations between indoor environmental quality in Dutch schools and pupils' health, also taking into account the children's home environment and personal factors. A cross-sectional study was performed in 11 classrooms in 11 different schools in the Netherlands. The study included exposure measurements, building inspections, and a questionnaire survey on pupils' health and domestic exposure. Principal Component Analysis (PCA) and non-parametric tests were performed to assess relationships. None of the schools complied with all indoor environmental quality standards. The importance of both the school and the domestic environment to pupils' health is shown in a multivariate analysis. If both the school and the home environment are highly polluted, improving conditions at school alone may not result in improved health of the children.

Keywords: building characteristics, building stock, health, indoor air quality, Principal Component Analysis (PCA), schools

Aux Pays-Bas, la loi oblige les enfants à passer 15% de leur temps dans un environnement scolaire. On sait que l'intérieur des écoles primaires hollandaises est sub-standard. En revanche, on ne sait pas précisément dans quelle mesure la santé des élèves est affectée par leur environnement scolaire intérieur. L'objectif de cet article est d'évaluer les relations qui existent entre la qualité de l'environnement intérieur des écoles hollandaises et la santé des élèves, en tenant compte également de l'environnement du foyer de ces enfants et de facteurs personnels. Une analyse en coupe a été exécutée dans 11 salles de classe de 11 écoles différentes des Pays-Bas. Cette étude englobait les mesures d'exposition, des inspections des bâtiments et un questionnaire sur la santé des élèves et leur exposition aux conditions domestiques. Pour évaluer ces relations, on a procédé à une analyse en composantes principales (ACP) et à des tests non-paramétriques. Aucune de ces écoles ne répondait aux normes de qualité environnementale intérieure. L'importance de l'environnement scolaire et domestique sur la santé des élèves est illustrée dans une analyse à variables multiples. Si l'environnement scolaire et l'environnement à la maison sont tous les deux très pollués, la seule amélioration des conditions dans les écoles risque de ne pas se traduire par une amélioration de la santé des élèves.

Mots-clés: caractéristiques des bâtiments, parc bâti, santé, qualité de l'air intérieur, analyse par composantes principales (APC), écoles

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Introduction

In the Netherlands, 8–12-year-old children are legally bound to spend 15% of their time in the school environment. The schools are typically occupied by a large number of pupils who produce pollutants such as carbon dioxide (CO_2), moisture, bioeffluents and dust. Moreover, building components, finishings, furnishings, building services and equipment contribute to the release of pollutants to indoor air (European Federation of Asthma and Allergy Associations (EFA), 2001). Adequate ventilation should remove these contaminants from indoor air.

Indoor air quality is known to affect human health, comfort, performance and productivity (Wargocki *et al.*, 2000, 2002; Sundell, 2001).

The impact of indoor air quality on children is of particular concern since children are generally more sensitive to environmental pollutants than are adults. Moreover, learning performance might be affected by a poor indoor air quality, with consequences to both the child and society (Landrigan, 1997; European Federation of Asthma and Allergy Associations (EFA), 2001; Mendell and Heath, 2005).

Several authorities and researchers have conducted measurements in Dutch primary schools. Van de Sandt *et al.* (1987) assessed CO_2 concentration and air temperature in seven primary schools in Rotterdam between April and May 1986. They showed that the CO_2 concentrations exceeded 1000 ppm for 36–98% of the time, with a median of 80%. Wassing (2003) conducted measurements in 16 classrooms of eight primary schools in the city of Groningen in February and March 2003. CO_2 concentrations exceeded 1000 ppm in 21–86% of teaching hours, with a median of 77%. Similar results were found in the regions of the cities of Arnhem and Geleen by the community health service (GGD) (Dolman and Peters, 1995; Van Buggenum, 2004). Janssen *et al.* (1999) investigated mass concentration and elemental composition of airborne particles smaller than 10 μm in diameter (PM_{10}) in two Amsterdam primary schools. The researchers found that PM_{10} mass concentrations were considerably higher in classrooms than outdoors.

Although indoor environmental problems in schools in the Netherlands are serious and well-documented, this is not only a Dutch issue. Daisey *et al.* (2003) report problems from several European and North American countries. Many classrooms were not adequately ventilated, and levels of specific allergens in deposited dust were often high enough to cause allergic symptoms in atopic occupants.

The present study assesses the relationships between indoor environmental quality in Dutch schools and pupils' actual health. It focuses on a range of indoor environmental parameters and building characteristics, also taking into account domestic exposure and personal factors of the pupils.

Methods

This study focuses on primary school buildings that are situated in the urban area of Eindhoven, the Netherlands, and that have at least one classroom used by 9–10-year-old children. In 2003, a number of the 121 school buildings in the region met these criteria. The study aimed at a participation rate of 12 schools, which is 10% of the total number of schools. A random sample on 16 schools was drawn in three terms ($n = 12$, 2 and 2) with the use of the Microsoft Excel 2000 Data Analyses tool. The principals of the schools were requested to participate, and 11 of them agreed. Per school, one classroom with 9–10-year-old children was selected by the headmaster and teachers in order to participate in the field survey.

Field survey

The field survey consisted of building inspections, exposure measurements and a questionnaire survey of pupils' health. This was carried out between January and March 2004, since winter time presents a worst case situation in terms of indoor air quality. Due to the low outdoor air temperatures in winter, windows were expected to be kept closed, resulting in low air change rates.

The characteristics of the buildings were obtained by a checklist investigation with the assistance of principals, caretakers and teachers. The checklist included questions on school characteristics, building dimensions, cleaning frequency, building services, interior decoration and pollution sources present in the classroom.

Cleaning was judged according to the 'Cleaning Frequency Tables 2002' of the Dutch Ministry of Education, Culture and Science (Dutch Ministry of Education Culture and Science, 2002). This tool distinguishes standard, extra and substandard cleaning based on the requested cleaning frequency of eight different cleaning issues. Unfortunately, it is not reported who did the actual cleaning: professionals or pupils. Furthermore, cleaning frequency is not a measure quality of cleaning.

Exposure measurements concerned indoor air quality, thermal comfort and biotic agents. The following parameters were measured:

- air temperature (°C): registered by Rense temperature transmitters and pt-1000s

- globe temperature (°C): measured by pt-100 globe thermometers
- air velocity (m/s): measured by a Schmidt SS 20.01 omnidirectional air velocity sensor based on thermal cooling of the sensor tip
- relative humidity (%): registered by a Rense thin-film capacitive sensor
- CO_2 concentration (ppm): measured by a Vaisala GMW 22 silicon-based non-dispersive infrared sensor
- airborne particles in the size ranges ≥0.3 and ≥1.0 μm (counts/min): measured by a MetOne R4903 two-channel (≥0.3 and ≥1.0 μm) optical particle counter with a continuous airflow of 0.14 l/min

The parameters were logged at 6-minute interval over 2 weeks. The measurement set-up was placed at a central location in the classroom.

Settled floor dust samples were obtained by a Hoover 700-W commercial vacuum cleaner at 9×1 m^2 scattered over the classroom floor area. Sampling time was defined by the type of floor covering. In the case of hard floors, all visible dust was taken. In case of carpets, each m^2 was hovered for 2 min. Dust was collected in a standard dust bag. Collection took place at the end of the measurement period in March 2004.

Dust samples were analysed at the laboratory of the Institute for Risk Assessment Sciences (IRAS), Utrecht, the Netherlands. Dust mite allergens (Der p1 and Der f1) and cat allergen (Fel d1) were measured using IndBiotech assays; endotoxin was measured with use of H_2O/Tween.

The health of the pupils was assessed by questionnaires, which were completed by both the pupils and their parents. The questionnaire survey was conducted after the measurement period. One school did not want to participate in the questionnaire survey.

The children's questionnaire, adapted from Van de Sandt *et al.* (1987), reviewed the acute health complaints of pupils. The presence of symptoms was examined by standardized questions and a four-point frequency scale (Figure 1). The children occupying the investigated classrooms were able to complete the questionnaire themselves. Questions and answering possibilities were read out in class.

The parents' questionnaire focused on the children's domestic environment, including questions about exposure to environmental tobacco smoke, dampness and mould growth, as well as the prevalence of asthma and atopic eczema. This questionnaire was adapted from the International Study of Asthma and Allergies in Childhood (ISAAC) (1998). Both the children's questionnaire and the questionnaire for their parents were handed out simultaneously. The parents' questionnaire needed to be completed and returned to the school within two weeks.

Did you perceive <*symptom*> last week at school/last weekend at home?

(1) Not at all
(2) Sometimes
(3) Often
(4) All the time

Figure 1 Children's questionnaire: question and the four-point frequency scale used to examine the presence of symptoms among children

Data analysis

Analysis of the associations between building characteristics, indoor environmental exposure and the health of the pupils was performed with non-parametric and multivariate statistical methods. The statistical analysis tool SPSS 12.0.1 was used.

Analysis of measured data on indoor environmental exposure focused on the hours that children were present in class. These hours were obtained from the schools' timetables. The first day of measurements was not considered because of the possible bias introduced by the intervention.

Questionnaire data on the health of the children were aggregated in six variables representing symptoms of a certain type: nasal, ocular, oropharyngeal, cutaneous, respiratory and general health symptoms (European Concerted Action (ECA) 'Indoor Air Quality & Its Impact on Man', 1989). The prevalence of symptoms was assumed in case of answers (3) 'Often' and (4) 'All the time'. Moreover, atopy was considered in further analysis. Children were classified as atopic or non-atopic on the basis of their parents' questionnaire. It was decided on 'atopic' if the answer was positive in at least three out of six questions on the prevalence of symptoms in the last 12 months, or when parents reported allergies to dust mites, pets or pollen. The label 'non-atopic' was given if the answer was negative on all questions.

Non-parametric statistics were employed to test whether symptom prevalence differed between schools; between schools grouped by building characteristics; between school and the domestic environment; and between atopic and non-atopic children. Mann–Whitney *U*-tests were used to examine differences between two independent samples. With the Kruskall–Wallis *H*-test, possible differences between multiple independent samples were assessed. In both tests, a confidence level of 0.05 was used.

Multivariate analysis was performed by Principal Component Analysis (PCA) (Jolliffe, 1986). PCA was used to detect structures in the relationships between variables concerning building characteristics, the indoor environment, domestic exposure and the health of the children. When performing a PCA, the variables were distributed in an x-dimensional space. Rotation of the original space is used to extract components explaining the total variance. Within the derived components, the importance of each variable is shown by the eigenvalue. PCA requires independent or normally distributed (or dichotomous) variables. Hence, parameters that were not normally distributed required transformation ($\ln(X + a)$). Due to extensive variation between duplicates in the endotoxin level analyses, this variable was excluded from further analysis.

The components that together explain 70% of the total variance were considered and interpreted. Within the interpretation of the extracted components, eigenvalues $\geq |0.45|$ were considered since this was the distinct break of all eigenvalues.

Results

The schools were built between 1930 and 2002 (mean age of 32 years). The number of pupils occupying each classroom ranged from 16 to 27 (mean of 22). The size of the classrooms varied from 48 m^2 (157 m^3) to 69 m^2 (232 m^3). This resulted in a mean occupation density of 8.4 m^3 per person, ranging from 5.9 to 13.8 m^3 per person. Three of the classrooms had a mechanical exhaust system; the others had natural ventilation. A hard floor covering was present in five classrooms, and six floors were covered with carpets. Visible signs of dampness were found in two classrooms, of which one showed distinctive mould growth. Two schools had substandard cleaning programmes, whereas three schools had extra cleaning programmes. The remaining schools had standard cleaning regimes.

Medians and ranges of the indoor environmental parameters measured in the classrooms are shown in Table 1. The indoor environment in the examined classrooms was generally substandard in relation to (inter)national standards and the following guidelines: ASHRAE 62-2001 (American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2001), CEN-CR 1752 (European Committee for Standardization (CEN), 1998), ISO 7730 (International Organization for Standardization (ISO), 1994), and NEN 1089 (Nederlands Normalisatie Instituut, 1986).

Table 1 Exposures in 11 classrooms

Exposure factor	$\overline{X}_{median}$	$\overline{X}_{min} - \overline{X}_{max}$
Air temperature (°C)	20.9	19.6–22.4
Mean radiant temperature (°C)	20.7	18.4–22.2
Relative humidity (%)	44.6	38.4–59.7
Air velocity (m/s)	0.08	0.05–0.10
CO_2 concentration (ppm)	1524	888–2112
Airborne particles $\geq$0.3 μm (counts/min)	22 829	15 560–44 071
Airborne particles $\geq$1.0 μm (counts/min)	944	650–2522
Mite allergen Der p1 (ng/g)	<30	<30.0–315.9
Mite allergen Der f1 (ng/g)	<30	<30.0–89.2
Cat allergen Fel p1 (mU/g)	20.9	9.6–83.5
Endotoxin (EU/g)*	9779	2896–21 084

Note: *Due to extensive variations in duplicate tests, endotoxin levels were excluded from further analysis.

The mean CO_2 concentration in the classrooms during school hours had a median of 1524 ppm, with means ranging from 888 to 2112 ppm. Schools showed CO_2 concentrations above 1000 ppm between 23 and 99% of the time (a median of 85%) during school hours, and above 800 ppm (the hygienic limit for persons with sensitive airways; Seppänen *et al.*, 1999) between 73 and 100% of the time (a median of 93%) (Figure 2).

In most samples, the concentrations of dust mite allergen Der p1 and Der f1 did not reach the limit of detection (LOD) of 30 ng/g. However, Der p1 clearly existed in one school. Cat allergen Fel d1 and endotoxin were detected in all floor dust samples. Although more dust was found on carpeted floors, higher allergen levels were not detected in comparison with non-carpeted floors.

Questionnaires were delivered to 228 pupils and their parents. The children's questionnaire resulted in a

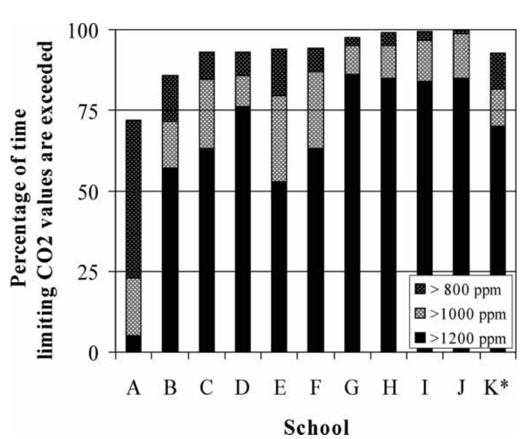

Figure 2 The percentage of time using carbon dioxide values of 800, 1000 and 1200 ppm is exceeded in each of the schools. *School K did not participate in the questionnaire survey

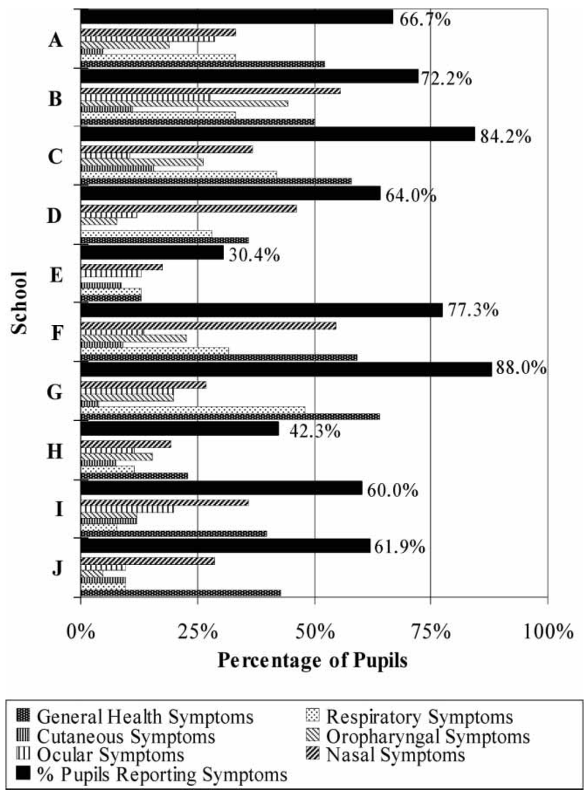

Figure 3 Health symptoms reported by the pupils

response rate of 99%; a response rate of 96% was achieved for the parents' questionnaire.

The main results of the children's questionnaire are shown in Figure 3. The percentage of pupils per school reporting symptoms varied between 30 and 88%, showing significant differences among the schools ($p = 0.000$). Differences were also found among the percentages of pupils reporting oropharyngeal ($p = 0.010$), respiratory ($p = 0.005$), and general health symptoms ($p = 0.005$). However, these differences were not associated with single building characteristics, such as the types of ventilation or floor covering (Table 2).

In this study, 14% of the pupils were classified as atopics; the percentage of non-atopics was 61%. The remaining 25% could not be classified in any group. Mann–Whitney *U*-tests did not show differences between the percentage of atopics or non-atopics in terms of reported symptoms (Table 3). No differences were found between the prevalence of symptoms at school or at home either for all pupils or for atopics and non-atopics (Table 4).

PCA resulted in eight components explaining the total variance. The five components that describe 70% of variance are shown in Table 5:

- Component 1 (explaining 20.7% of variance): indicates that atopic children occupying dusty schools and living in old, damp houses with mould growth have a higher symptom prevalence. Furthermore, pupils are reporting more oropharyngeal symptoms in these circumstances. High concentrations of airborne particles seem to originate from several pollution sources, such as plants in class, blackboard chalk, open bins and unvented copiers. These schools are associated with increased mean radiant temperatures.

- Component 2 (17.6% of variance): makes it clear that air pollution at school is associated with air pollution at home. The presence of an unvented gas-operated water heater in the kitchen (a kitchen geyser) seemed an important factor at home. Increased levels of CO_2 and humidity seemed to be the main factors at school. No associations were found with the health of the pupils.

- Component 3 (14.6% of variance): indicates that newer school buildings with carpeted floors, a higher cat allergen concentration and fewer dust reservoirs (such as televisions, open shelves and indoor sun blinds) are associated with an absence of dampness in the dwelling. No associations were found with the health of the pupils.

- Component 4 (13.8% of variance): indicates that a high symptom prevalence among children is

Table 2 Results of non-parametric statistics (Mann–Whitney *U*-test and Kruskall–Wallis *H*-test): differences between the percentage of symptoms reported and building characteristics

Building characteristics	Symptoms					
	Nasal	Ocular	Oropharyngeal	Cutaneous	Respiratory	General health
Type of ventilation	0.517	0.117	0.833	0.833	0.667	0.517
Type of floor covering	0.610	0.476	0.476	0.914	0.352	0.114
Cleaning frequency	0.756	0.567	0.881	0.537	0.840	0.437
Year of classroom construction	0.743	0.759	0.743	0.794	0.750	0.616

Note: Data are *p*-values, $\alpha = 0.050$.

Table 3 Results of the Mann–Whitney *U*-test: differences between symptoms reported by atopic and non-atopic children, all schools and per school.

School	Symptoms					
	Nasal	Ocular	Oropharyngeal	Cutaneous	Respiratory	General health
All schools	0.836	0.301	0.772	0.468	0.821	0.224
A	1.000	0.497	1.000	1.000	1.000	1.000
B	1.000	0.491	0.523	1.000	0.523	1.000
C	1.000	1.000	1.000	0.257	0.467	0.143
D	0.200	0.371	1.000	1.000	0.505	1.000
E	1.000	0.350	1.000	1.000	0.350	0.350
F*						
G	1.000	1.000	1.000	1.000	1.000	0.438
H	0.651	0.526	1.000	0.557	1.000	1.000
I	1.000	0.599	1.000	1.000	1.000	0.228
J	1.000	0.294	0.294	1.000	1.000	0.593

Notes: Data are *p*-values, two-tailed, $\alpha = 0.050$.
*None of the pupils in school F was classified as atopic.

associated with factors such as condensation on windows, the presence of dusty chalk, high maximum air velocities at school, small classroom floor surfaces and domestic exposure to environmental tobacco smoke.

- Component 5 (11.1% of variance): shows that classrooms without local temperature control and indoor sun blinds are associated with higher indoor air temperatures and an increased absolute humidity. This is associated with a decrease in cutaneous symptoms.

Discussion

This study confirms that the indoor environment of Dutch primary schools is poor. In all schools, indoor air quality exceeded the criteria set in current standards. This is a result of inadequate ventilation and a high occupant density in the classrooms.

Nevertheless, pupils' health appears to be associated with both school and domestic exposure. No differences were found between the number of symptoms reported in both environments by neither all pupils, nor atopic or non-atopic children only. The characteristics of the dwelling and domestic exposure show up in several components of the PCA. The results of the PCA indicate the complexity of the relation between (1) the indoor environment and (2) building characteristics of primary schools, as well as (3) domestic exposure and (4) the health of pupils. Pollution of both the classroom (high concentrations of particulate matter and the presence of dust sources) and dwellings (domestic mould growth and dampness) seems to be the major factors for pupils' health (Components 1 and 4). This is

Table 4 Results of the Mann–Whitney *U*-test: differences between symptoms reported in the school and domestic environment.

School	Pupils	Symptoms					
		Nasal	Ocular	Oropharyngeal	Cutaneous	Respiratory	General health
All schools	all pupils	0.328	0.602	0.601	1.000	0.743	0.442
	non-atopic	0.608	0.401	1.000	1.000	0.563	0.212
	atopic	0.596	1.000	1.000	1.000	1.000	0.567
A	all pupils	0.751	1.000	1.000	1.000	0.734	0.756
B	all pupils	0.289	1.000	0.733	1.000	1.000	1.000
C	all pupils	0.743	1.000	1.000	1.000	1.000	1.000
D	all pupils	1.000	1.000	1.000	1.000	0.496	1.000
E	all pupils	0.665	1.000	1.000	1.000	1.000	0.448
F	all pupils	1.000	0.607	1.000	1.000	1.000	0.547
G	all pupils	0.377	0.702	0.702	1.000	1.000	0.256
H	all pupils	1.000	0.610	1.000	1.000	1.000	1.000
I	all pupils	1.000	1.000	0.609	0.702	0.667	0.769
J	all pupils	1.000	0.663	0.184	1.000	1.000	1.000

Notes: Data are *p*-values, two-tailed, $\alpha = 0.050$.

Table 5 Results of principal component analysis and interpretation of the data. The five components explaining >70% of the variance, as well as eigenvalues $\geq |0.45|$ are shown. Varimax with Kaiser Normalization is used as the rotation method, rotation converged after 19 iterations. Missing values are excluded listwise.

Component 1 20.7% (20.7)[a]		**Component 2** 17.6% (38.3)		**Component 3** 14.6% (52.9)		**Component 4** 13.8% (66.7)		**Component 5** 11.1% (77.8)	
Atopic children occupying dusty classrooms and living in damp houses report more symptoms		In schools with indoor air pollution children are also exposed to air pollution at home		Newer schools with carpets, more cat allergen, and fewer dust reservoirs are associated with the absence of domestic dampness		High symptoms prevalence among children is associated with various school and domestic factors		Classrooms without local temperature control are warmer and are associated with a decrease of skin symptoms	
A. Building characteristics and indoor environment school									
ABP $\geq$ 0.3 μm, maximum	0.99	CO_2, maximum	0.91	Year of construction school	0.96	Air velocity, maximum	0.61	Air velocity, SD	0.86
ABP $\geq$ 0.3 μm, SD[b]	0.98	CO_2, median	0.87	Cat allergen Fel d1 sample 1	0.88	Condensation	0.53	MRT, minimum	0.86
MRT, maximum	0.89	Window surface	0.85	Cat allergen Fel d1 sample 2	0.84	Use of dust-free chalk	−0.46	Orientation west	0.78
ABP $\geq$ 0.3 μm, median	0.84	CO_2, SD	0.85	Door surface	0.77	ABP $\geq$ 1.0 μm, minimum	−0.52	Air temperature, median	0.76
MRT, median	0.72	Operable windows	0.83	Mechanical exhaust toilets	0.70	Insulating window panes	−0.55	Air temperature, minimum	0.74
Plants in class	0.68	Absolute humidity, median	0.79	Carpeted floors in class	0.66	CO_2, minimum	−0.56	Air temperature, maximum	0.64
Absolute humidity, SD	0.64	Absolute humidity, maximum	0.72	Standard cleaning	0.60	Floor surface	−0.64	MRT, SD[b]	0.63
Open paper bin	0.57	CO_2, minimum	0.60	Year of construction class	0.50			Absolute humidity, maximum	0.62
ABP $\geq$ 1.0 μm, maximum	0.50	Settled floor dust	0.51	Separate copy room	0.50			Indoor sun blinds present	0.61
Open dust bin	0.48	Condensation	0.47	Substandard cleaning	−0.45			Mechanical exhaust toilets	0.55
Television in class	0.45	Number of VDUs	0.45	Indoor sun blinds present	−0.66			Absolute humidity, SD	0.51
Mechanical exhaust corridors	−0.49	Insulating window panes	−0.46	Television in class	−0.71			MRT, median	0.49
Floor surface	−0.53	Sink in class	−0.76	Length of open shelves[b]	−0.89			Furniture>3 years old	−0.47
Use of dust-free chalk	−0.57	Absolute humidity, minimum[b]	−0.81					CO_2, minimum	−0.47
Air temperature, SD	−0.58							Air velocity, minimum	−0.53
MRT, SD[b]	−0.59							Orientation North	−0.57
Volume of class	−0.71							ABP $\geq$ 1.0 μm, minimum	−0.62
Ventilated copy room	−0.81							Local temperature control	−0.68
Separate copy room	−0.82								

(*Table continued*)

Table 5 *Continued*

Component 1 20.7% (20.7)[a]		**Component 2 17.6% (38.3)**		**Component 3 14.6% (52.9)**		**Component 4 13.8% (66.7)**		**Component 5 11.1% (77.8)**	
B. Domestic environment (percentage of dwellings)									
Construction <1944	0.70	Unvented kitchen geyser	0.78	Construction 1945–74	0.63	Exposure to tobacco smoke	0.59		
Dampness	0.67			Construction <1944	−0.51	Construction > 1975	−0.51		
Mould growth[b]	0.48			Dampness	−0.66				
Rugs in living room	0.46								
Construction >1975	−0.52								
C. Health of Pupils (percentage symptoms reported)									
Symptoms atopics	0.79					Symptoms non-atopics	0.97	Cutaneous symptoms	−0.65
Oropharyngeal symptoms	0.51					Symptoms pupils	0.95		
						General health symptoms	0.93		
						Respiratory symptoms	0.92		
						Nasal symptoms	0.61		
						Oropharyngeal symptoms	0.56		

Notes: [a]Percentage of variance (cumulative in parenthesis).
[b]Transformation applied. ABP, airborne particles; MRT, mean radiant temperature; VDU, video display unit.

reasonable since both the school and domestic environment are closely integrated in children's daily lives. Furthermore, schools and dwellings are usually erected in the same period and are located in the same neighbourhood. This is shown in Component 3.

During school time, children spend 77% of their day in a domestic environment (Van Lynden-Van Nes, 1999) versus 15% at school. The indoor environment in Dutch schools is generally substandard, but the indoor environment in dwellings is also most likely to be poor. In the domestic environment children are possibly exposed to pollutants that are not present in the school environment, such as pets, tobacco smoke and other combustion products. Moreover, exposure to mite allergens greatest in the domestic environment (Zock and Brunekreef, 1995; Amr *et al.*, 2003). Upholstered furnishings, carpets and curtains that are present in the dwellings constitute reservoirs for allergens and settled dust. Classical allergen-avoidance measures in dwellings do not result in sufficient exposure reduction (Van Lynden-Van Nes, 1999). The fact that no difference was found between the prevalence of symptoms at home and at schools supports the importance of the domestic environment.

The relation of school dust and domestic dampness, on one side, and symptom prevalence among atopic children, on the other, appears from Component 1. However, no differences were found between the prevalence of symptoms among atopic and non-atopic children in non-parametric statistics. The PCA focused on groups of children as a whole, while bivariate statistics only studied individuals. The use of medication to avoid the occurrence of symptoms lessens the differences between the two groups of children. The medication children had used before answering the questionnaires was not reported.

Neither non-parametric statistics nor the PCA showed any importance of cleaning frequency, the presence of mechanical or natural ventilation, or the type of floor covering in the classroom with regard to symptom prevalence among pupils. Changing any of these building characteristics, however, might influence the quality of the indoor air.

To achieve an excellent indoor environment in schools, air change rates should be increased without having a negative influence on thermal comfort, e.g. draughts. An awareness of the need of ventilation and user-friendly control of the ventilation equipment are of major importance. In future schools, the use of intelligent systems should be considered. The interior of the school, as well as building services, should be designed to be easily reachable for cleaning and maintenance to prevent the accumulation of dust. The use of low-emitting building materials should be encouraged. In case of both highly polluted domestic and school indoor environments, improving conditions at school alone is not expected to result in improved health conditions of the children, not even for atopic children in whose dwellings allergen-avoidance programmes have been executed, since the execution of these programmes in homes alone appears insufficient (Van Lynden-Van Nes, 1999). Nevertheless, some individuals might benefit from improved indoor environmental quality in school (Zock and Brunekreef, 1995). This does not mean one is free to keep the indoor environment in schools as it is.

Conclusions

The present study confirms that indoor air quality in primary schools in the Netherlands is poor; carbon dioxide concentrations are extremely high. Results of the Principal Component Analysis showed that pollution of both the classroom and dwellings are major factors with regard to pupils' health. This indicates that both the school and the home environment need to be improved in order to achieve a healthy and comfortable environment for children.

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