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ORIGINAL PAPER

Indoor air quality in elementary schools of Lisbon in spring

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Abstract Analysis of indoor air quality (IAQ) in schools usually reveals higher levels of pollutants than in outdoor environments. The aims of this study are to measure indoor and outdoor concentrations of NO_2, speciated volatile organic compounds (VOCs) and carbonyls at 14 elementary schools in Lisbon, Portugal. The investigation was carried out in May–June 2009. Three of the schools were selected to also measure comfort parameters, such as temperature and relative humidity, carbon dioxide (CO_2), carbon monoxide (CO), total VOCs, and bacterial and fungal colony-forming units per cubic metre. Indoor concentrations of CO_2 in the three main schools indicated inadequate classroom air exchange rates. The indoor/outdoor (I/O) NO_2 ratio ranged between 0.36 and 0.95. At the three main schools, the total bacterial and fungal colony-forming units (CFU) in both indoor and outdoor air were above the advised maximum value of 500 CFU/m^3 defined by Portuguese legislation. The aromatic compounds benzene, toluene, ethylbenzene and xylenes, followed by ethers, alcohols and terpenes, were usually the most abundant classes of VOCs. In general, the indoor total VOC concentrations were markedly higher than those observed outdoors. At all locations, indoor aldehyde levels were higher than those observed outdoors, particularly for formaldehyde. The inadequate ventilation observed likely favours accumulation of pollutants with additional indoor sources.

Keywords Carbon dioxide · Carbon monoxide · Carbonyls · Indoor air quality · Nitrogen dioxide · Schools · Volatile organic compounds

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Introduction

Human exposure occurs when a person comes into contact with a pollutant of a certain concentration during a certain period of time (Ott et al. 2007). This means that exposure requires both the pollutant and the person to be present. People can be exposed to contaminants by inhalation, ingestion and dermal contact. In the past, scientists have paid much attention to the study of exposure to outdoor air contaminants, because they have realised the seriousness of outdoor air pollution problems. However, each indoor microenvironment has unique characteristics, determined by the local outdoor air, specific building characteristics and indoor activities. Consequently, each individual's personal exposure will be determined by the different

indoor micro-environments to which the person is exposed, and the time spent in each (Stranger et al. 2007).

Many studies are being conducted on indoor air pollution, because most people spend a lot of their time indoors, living, working, and studying (Lee et al. 2001a, 2002a, b; Li et al. 2001). Reports about buildings with air-related problems have received increasing attention since the 1970s (Hodgson 1992; Spangler and Sexton 1983). Sick building syndrome (SBS) is a commonly used term for symptoms resulting from problems with indoor air quality (IAQ). Complaints common to SBS include allergic rhinitis, headaches, flu-like symptoms, watering of eyes and difficulty in breathing (Mishra et al. 1992). The first official study about SBS that examined more than one structure was published in 1984 (Finnigan et al. 1984).

IAQ problems in schools may be even more serious than in other categories of buildings, due to higher occupant density and insufficient outside air supply, aggravated by frequent poor construction and/or maintenance of school buildings. Therefore, odour and comfort complaints have been related to IAQ problems in schools, as well as increased incidence of allergic, asthma and infectious diseases. Poor IAQ can also affect scholarly performance and attendance, since children are more vulnerable than adults to health risks from exposure to environmental hazards (Daisey et al. 2003; Godoi et al. 2009). The significance of IAQ in schools is underscored by the large number of studies worldwide (Blondeau et al. 2005; Chew et al. 2005; Godoi et al. 2009; Godwin and Batterman 2007; Griffiths and Eftekhari 2008; Hodgson et al. 2004; Kim et al. 2007; Klinmalee et al. 2009; Lee and Chang 2000; Meklin et al. 2002; Mukerjee et al. 2009; Shendell et al. 2004; Sohn et al. 2009; Stranger et al. 2008; Zhang et al. 2006). However, most of these studies concentrate on a specific group of pollutants or on thermal conditions. Multidisciplinary indoor field campaigns, measuring a wide range of health-relevant chemical and physical properties, are still lacking. In Lisbon, the fraction of children with asthma and rhinitis is about 15% and 40%, respectively (Plácido 2004), and the school work environment has not received much attention. Therefore, IAQ in Portuguese schools is almost unknown. The main aims of this work are: (a) to measure indoor comfort parameters (temperature, relative humidity, CO, CO_2 and total VOCs) and bacterial and fungal contamination in three representative schools, (b) to evaluate VOCs, carbonyls and NO_2 gaseous pollutants, by passive sampling, in indoor and outdoor air at 14 schools, and (c) to identify possible sources, activities or other conditions contributing to the measured levels.

Materials and methods

Description of schools

Indoor and outdoor air samples were collected at 14 schools with wide geographical coverage representing the Lisbon urban area, in May and June 2009. Two classrooms from each of the 14 schools were selected for this study, all depending only on natural ventilation through doors and windows. Details of each sampling site are listed in Table 1.

Comfort parameters and airborne microorganisms

For measurement of comfort parameters and airborne microorganisms, 3 of the 14 schools were selected: schools A, B and C. These schools were previously considered representative of all the elementary-level educational institutions (Khan et al. 2007a, b). Continuous measurements of temperature, relative humidity (RH), CO_2 and total VOCs were performed with an automatic portable indoor air quality probe (IQ-610, GrayWolf® monitor) in one classroom of each school during the 8-h occupancy periods. This IAQ monitor includes a Pt100 probe for measuring temperature, a capacitance probe to sense RH and a CO_2 non-dispersive infrared sensor, all of them with an extremely fast response. The monitor also includes a photo-ionisation detector to track total VOCs over time. It displays measurements in real time, allowing logged data to be downloaded to WolfSense® personal computer (PC) software for analysis. The equipment was supplied with a factory calibration certificate, but it is checked prior to next use with appropriate calibration kits. Indoor CO_2 levels are an indicator of adequacy of outdoor air ventilation relative to indoor occupant density.

Bacterial and fungal colony-forming units per cubic metre of air (CFU/m^3) were monitored by liquid impinger sampling (May and Harper 1957) in the two classrooms and playgrounds during 1 day in

Table 1 Characteristics of each school

Characteristics	Schools													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Urban														
Environment	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Heating	×		×		×	×	×	×	×	×	×	×	×	×
Ventilation	Windows/doors													
Blackboard and chalk	×		×		×	×	×	×	×	×	×	×	×	×
Whiteboard with pen		×		×										
Ceramic tile floor	×	×	×	×		×	×		×					×
Vinyl floor					×						×	×		
Wood floor								×		×			×	
Animals inside		×					×	×	×					
Plants inside		×			×			×						×
Area (m^2)	64.51	46.82	50.14	51.2	47.0	62.68	63.7	50.08	36.5	50.34	48.36	51.2	49.8	46.7
Height (m)	3.70	3.50	3.50	3.20	3.15	3.40	3.00	3.20	2.23	3.20	3.80	3.20	3.70	2.64

each one of the three main schools. The flow rate was set at 2.5 L/min. At each sampling location (classrooms and playgrounds), 1-h samples were taken. To obtain representative results, five replicates were obtained per site.

Sampling and analysis of VOCs, carbonyls and NO_2

VOCs and carbonyls were sampled in parallel using Radiello® (Fondazione Salvatore Maugeri, Padova, Italy) diffusive passive tubes (cartridge codes 130 and 165, respectively) for 14 consecutive days. At each sampling location, for each one of these two groups of compounds, two replicate samples were collected. Indoor samples were collected at height of about 1.5 m above the floor. The diffusive samplers were positioned at a distance exceeding 1 m from any window or door. Outdoor passive samples were collected at height of about 2 m above the ground. The VOC adsorbing cartridges consist of 60-mm-long stainless-steel net cylinders, with 100 mesh grid opening and 5.8 mm diameter, packed with 530 ± 30 mg activated charcoal with particle size of 35–50 mesh (Cocheo et al. 1996).

VOCs were extracted from the exposed samplers with 2 mL carbon disulphide (CS_2 from Aldrich) containing 2-fluorotoluene (from Aldrich) as internal standard. The glass vials were shaken for approximately 30 min. The analyses of the extracts were performed by gas chromatography (Chrompack CP 9001) coupled to a flame ionisation detector (GC/FID), using nitrogen carrier gas at constant pressure of 20 psi. A 100% dimethylpolysiloxane column (0.2 mm, 50 m, film thickness 0.5 μm) was used. The temperature program was as follows: 50°C for 5 min, 5°C/min up to 80°C, 15°C/min up to 135°C, 20°C/min up to 220°C, final isotherm for 20 min. Injector and detector temperatures were 240°C and 300°C, respectively. The equipment was calibrated before and during the analyses of samples by injecting standard solutions of all compounds identified in CS_2, specifically: pentane, *n*-hexane, cyclohexane, *n*-heptane, *n*-butyl acetate, styrene, α-pinene, sabinene, β-pinene, *n*-decane, (+)-3-carene, limonene (all from Fluka), methyl acetate, ethyl acetate, isooctane, *m*+*p*-xylene, *o*-xylene (all from Merck), benzene (AnalytiCals), toluene (Lab-Scan) and γ-terpinene (Aldrich). Four standard solutions, each one containing five compounds in CS_2, were prepared. The analytes in these four standard solutions were present at concentrations of 40, 20, 10 and 5 ng/μL. The limit of detection was calculated for ethyl acetate, cyclohexane, isooctane, *n*-heptane, toluene, *n*-decane and limonene. Depending on the analyte, the limit of detection [$LOD = 3.3(s/S)$, where s is the STDEV of areas and S is the slope] ranged from 0.34 to 2.52 ng/μL (Pegas et al. 2010), corresponding to environmental concentrations between 0.27 and 2.97 μg/m^3.

Carbonyls collected in cartridges filled with 2,4-dinitrophenylhydrazine reacted to give the corresponding 2,4-dinitrophenylhydrazones. These were extracted with 2 mL acetonitrile (Fisher Scientific). The glass vials were shaken for approximately 30 min, and the extract filtered through 0.45-μm disc membrane filters (filtration kit RAD 174) and injected into the high-performance liquid chromatography (HPLC) system. The analytical system consisted of a Jasco PU-980 pump, a Rheodyne manual injection valve (sample loop of 20 μL), a Supelcosil LC-18 column (250 × 4.6 mm, 5 μm; Supelco) and a Jasco MD-1510 diode array detector, all connected in series. Isocratic elution at room temperature was performed using acetonitrile/water solution (60/40, v/v) as the mobile phase at flow rate of 1.5 mL/min. The carbonyl concentrations were quantified using external calibration curves constructed from standard solutions of TO11/IP6A carbonyl—DNPH Mix (Supelco). The limit of detection (LOD) ranged from 1.29 to 2.09 μg/mL, depending on the analyte.

NO_2 concentrations were also passively monitored for 14 days. The diffusive tubes (with steel grids impregnated with triethanolamine) chemiadsorb NO_2, as nitrite, which was quantified by visible spectrophotometry (Bhugwant and Hoareau 2003).

Results and discussion

Comfort parameters and airborne microorganisms

The daily variation of comfort parameters throughout the 2-week monitoring period was recorded. To illustrate contrasting conditions, two specific days were chosen to exemplify the daily profiles. The mean daily temperature and RH values during the monitoring period, taken at the three main schools, ranged from 21.9 ± 1.09°C to 25.9 ± 1.56°C and from 34.6 ± 3.49% to 56.2 ± 3.28%, respectively (Fig. 1). In general, the temperature varied between 18.6°C and 28.2°C, whereas RH was in the 25.1–66.8% interval. Thermal comfort requirements differ for each individual due to factors such as clothing, activity level, age and physiology. ANSI/ASHRAE standard 55–2004 (2004) describes the temperature and humidity ranges that are comfortable for 80% of people engaged in chiefly sedentary activities. These values were conceived for adults in office environments and presume "normal indoor clothing". The effects of moderate heat stress on performance of office work in subjects aged 18–29 years were evaluated through questionnaires by Witterseh et al. (2004). Raised temperature increased eye, nose and throat irritation ($P < 0.05$), headache intensity ($P < 0.05$) and difficulty in thinking clearly ($P < 0.01$) and concentrating ($P < 0.01$), and decreased self-estimated performance. Usually, the recommended indoor temperature ranges for comfort are 20–23°C in winter and 23–26°C in the summer. The suggested indoor RH values for comfort are in the range 30–60%. Control of RH also helps limit growth of microorganisms. Maintaining RH below 50% inhibits mould growth, dust mite infestation and bacteria. If RH levels fall below 25%, building occupants can experience respiratory irritation and possibly dry, itchy eyes and skin. Generally, in every school studied, the temperature and RH values were within the recommended ranges.

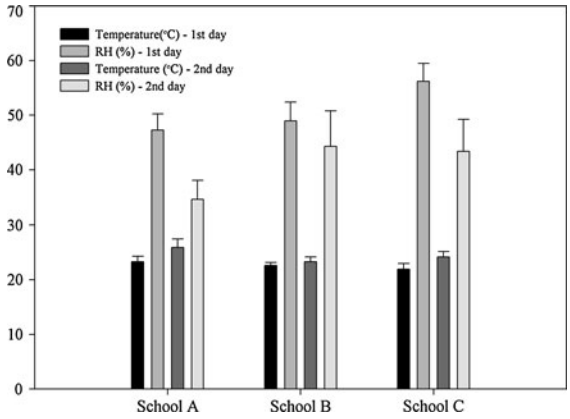

Fig. 1 Indoor daily mean temperature (°C) and relative humidity (RH, %). Bars indicate standard deviations (STDEV)

The National System for Energy and Indoor Air Quality Certification of Buildings (*Regulamento dos Sistemas Energéticos de Climatização de Edifícios*, RSECE) establishes an acceptable maximum value (AMV) of CO_2 of 1,800 mg/m^3 for buildings in Portugal (RSECE 2006). CO_2 levels ranged widely (705–6,821 mg/m^3) and exceeded 1,800 mg/m^3 in all three main schools. Carbon dioxide concentrations are often used as a surrogate for the rate of outside air supply per occupant. Indoor CO_2 levels above about 1,000 ppm are normally considered as indicative of ventilation rates that are unacceptable with respect to body odours. Concentrations of CO_2 below 1,000 ppm

do not always guarantee that the ventilation rate is adequate for removal of air pollutants from indoor sources (Daisey et al. 2003). The indoor concentrations of CO_2 showed inadequate classroom air exchange rates. Figure 2 depicts the variation of indoor CO_2 concentrations in a typical working day in the three main schools. Strong correlation of CO_2 levels with occupancy was observed. CO_2 spikes were even more pronounced when students started physical activities inside the classrooms, such as art classes or entrance from and exit to the playground. Seppanen et al. (1999) reviewed available literature for the association between both ventilation rates and CO_2 concentrations and health. The authors were not able to determine a clear threshold value for CO_2 below which further reductions in concentration were not associated with further decreases in SBS symptoms. However, 7 of the 16 studies reviewed suggested that the risk of SBS symptoms continued to decrease with decreasing CO_2 concentrations below 800 ppm. Above all, CO_2 measurements in schools indicate that most classrooms probably do not meet ANSI/ASHRAE standard 62–1999 (1999) for minimum ventilation rate of 2.5 L/s per person. Concentrations of a variety of pollutants emitted by occupants and building materials and furnishings will be higher under these conditions than if the ASHRAE ventilation standard were met. The potential for increased risks of contracting certain communicable respiratory illnesses, such as influenza and common colds, in classrooms with low ventilation rates is higher than in adequately ventilated places (Fisk 2001).

CO levels ranged from values below LOD to 1.0 mg/m^3 (Fig. 2) and did not exceed 12.5 mg/m^3, the recommended exposure limit (RSECE 2006). To prevent carboxyhaemoglobin levels in the blood from exceeding 2.5%, the World Health Organization (WHO) has set specific air quality guidelines for distinct averaging periods: 100 mg/m^3 (15 min), 60 mg/m^3 (30 min), 30 mg/m^3 (1 h) and 10 mg/m^3 (8 h) (Chaloulakou et al. 2003). CO is one of the most characteristic traffic pollutants usually observed in urban areas. However, in this study, concomitant increases of CO_2 and CO concentrations were observed. This suggests a linear correlation between CO and CO_2 ($r = 0.787$) and a direct relationship between increasing concentration and classroom occupancy. CO is produced as a by-product of incomplete combustion of organic materials. In the

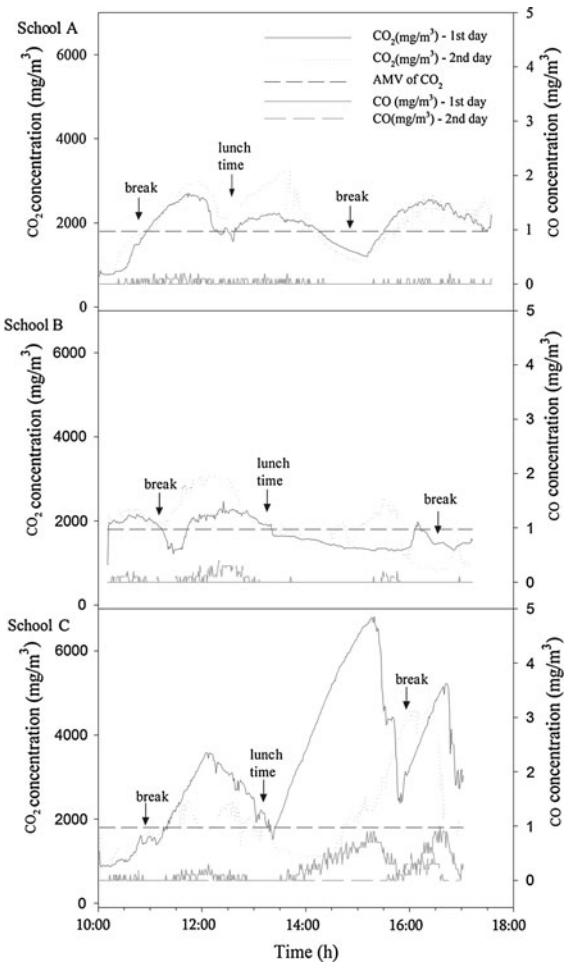

Fig. 2 Indoor carbon dioxide and carbon monoxide levels in the three main schools

human body, CO is produced endogenously by the class of enzymes known collectively as heme oxygenase (Mines 1997). CO is detectable in small quantities in the exhaled air of healthy people (Zayasu et al. 1997). Exhaled CO is increased in patients with inflammatory pulmonary diseases such as bronchial asthma, bronchiectasis, upper respiratory tract infections and seasonal allergic rhinitis (Zayasu et al. 1997). This is supported by the fact that inhaled corticosteroids inhibit the increase in exhaled CO in asthmatic patients (Zayasu et al. 1997). According to Jones and Lam (2006), human exposure to microenvironments with high CO levels can increase exhaled CO concentrations. Thus, exhaled CO levels can potentially act as a functional indicator of air pollutant levels. In the city of Lisbon the most common source

of total CO emissions is vehicle exhausts (Borrego et al. 2000). Taking into account the CO levels recorded by the three monitoring stations close to the three main schools, mean I/O ratios close to zero were obtained. The highest CO levels were registered in the school located near one of the busiest streets of Lisbon (Avenida da Liberdade). The average daily concentrations measured by the air quality monitoring station in this street were in the range 0.36–0.52 mg/m^3. Based on a comprehensive literature review, the INDEX project (Kotzias et al. 2005) concluded that current CO sources in European Union (EU) residences contribute essentially to short-term, rather than long-term, exposure.

Very few measurements of total VOCs in a typical school day are reported in the scientific literature (e.g. Pegas et al. 2009, 2010). Total VOC concentrations could give information about the influence of aerosol sprays, solvents, cleaning agents, pesticides, paints and repellents. The measurements ranged from the LOD (<0.005 mg/m^3) to 2.1 mg/m^3 and did not surpass the recommended value of 0.6 mg/m^3 (RSECE 2006) (Fig. 3). Peak concentrations of VOCs were observed around 10 a.m. at school A, on the first day, decreasing progressively thereafter. This may be explained by the fact that, on this particular day, classrooms were cleaned with VOC-release products in the morning, before classes started. Normally, the cleaning staff tidy up the rooms at the end of the day. An increase in concentrations was also observed at school B during a period coincident with an art class where glue and paints were in use. This shows that collage and painting materials can significantly enhance VOC levels in indoor air. Zhang et al. (2006) also identified a visual art classroom with a relatively high level of VOCs.

Table 2 presents indoor and outdoor average levels of total bacterial and total fungal CFU/m^3. In all schools, the total fungal and total bacterial colony-forming units in both indoor and outdoor air were above the AMV of 500 CFU/m^3 defined by Portuguese legislation (decree-law 79/2006; RSECE 2006). The main factors affecting atmospheric dispersion and survival of microorganisms are relative humidity, temperature, oxygen, wind and air turbulence, air pollutants and water and nutrient availability. Very high levels of microorganisms were obtained in all five replicates performed for every sampling site. Repetition of the whole experiment

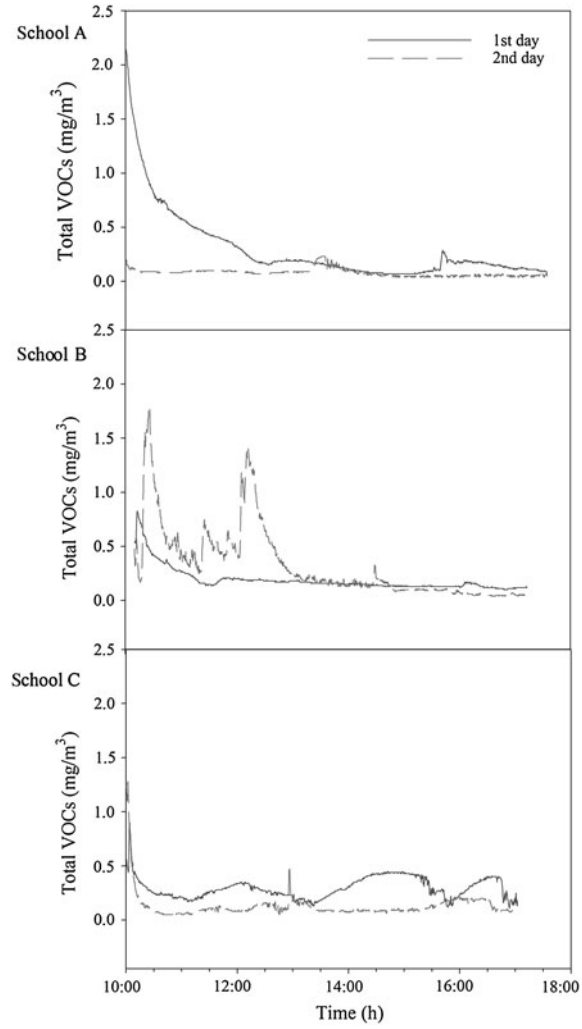

Fig. 3 Diurnal variation of total VOCs (non-methane hydrocarbons) in the three main schools

1 week apart (again with five replicates) was carried out to confirm the huge microbial counts. It was necessary to count some quadrants of the Micropore filters (0.45 μm) to extrapolate for all quadrants of each filter and estimate the minimum CFU number per sample. The high amounts of bacteria in both indoor and outdoor environments may derive from several factors, including high seasonal level of bioaerosols in outdoor air (spring), and human activities, such as breathing, sweating and movement causing particle resuspension.

High bacteria counts were probably due to high occupancy loading, poor hygienic condition of occupants, inadequate ventilation rates, movement of

Table 2 Measurement results for microorganisms

	Bacterial (CFU/m^3)	Fungal (CFU/m^3)
School A		
Indoor I	≥27,051	≥2,023
Outdoor	≥25,651	≥2,697
Indoor II	≥29,009	≥1,802
School B		
Indoor I	≥30,423	≥2,023
Outdoor	≥14,096	≥2,930
Indoor II	≥22,123	≥1,945
School C		
Indoor I	≥39,838	≥1,335
Outdoor	≥39,838	≥1,698
Indoor II	≥39,838	≥1,958

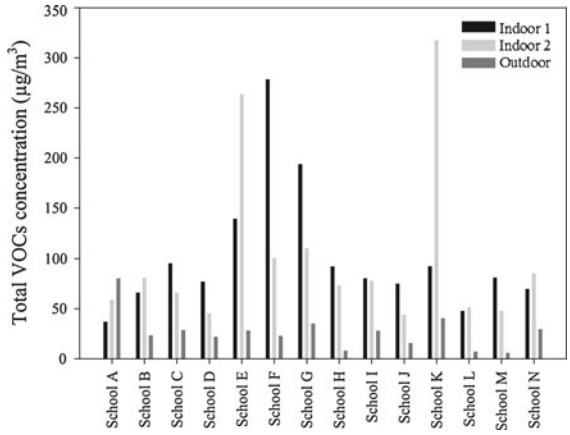

Fig. 4 Indoor (two classrooms) and outdoor VOC concentrations (sum of all compounds identified)

textiles, food products etc. (Lee et al. 2002; Mentese et al. 2009). Scheff et al. (2000) reported that, in a middle school of Springfield, the indoor fungal and bacterial counts were significantly higher than the outdoor concentrations. Similarly, Jo and Seo (2005) reported, for both total bacteria and total fungi, higher indoor concentrations compared with the outdoor environment at 11 elementary schools in Korea. Mentese et al. (2009) studied different indoor and outdoor environments in terms of bioaerosol contamination. The highest total bacteria counts were measured in kindergartens, elementary schools, restaurants, high schools and homes, while the highest mould levels were observed in kitchens, bathrooms and offices. Gonçalves et al. (2010) studied indoor and outdoor atmospheric fungal spores in the São Paulo metropolitan area (Brazil), and obtained levels above 36,000 CFU.

VOCs, carbonyls and NO_2

The aromatic compounds benzene, toluene, ethylbenzene and the xylenes, followed by ethers, alcohols and terpenes, were usually the most abundant classes of VOCs. Generally, indoor total VOC concentrations were markedly higher than those observed outdoors (Fig. 4, Table 3). The sum of the individual VOC concentrations in indoor air varied from 37 to 317 μg/m^3. Outdoor concentrations ranged between 6 and 80 μg/m^3. In general, all the different classes of VOCs presented higher concentrations indoors than outdoors. Ethanol, dichloromethane, 1,2-dichloropropane, propyl acetate methylcyclohexanol, 2,2-dimethylbutane and 4-methyl-2-pentanone were only found in the indoor air. Those compounds only detected in indoor air probably have an indoor source. Pollutants identified in both indoor and outdoor samples, but with higher concentrations in the indoor environments, may indicate additional indoor sources or inadequate ventilation ratios; for example, terpenes are well known as substances emitted from cleaning products and room fresheners (Singer et al. 2006). Additionally, α-pinene is an intrinsic component of wood and furniture (Yrieix et al. 2010). Other VOC sources in indoor air include cooking fuels, aerosol propellants, refrigerants, paints, varnishes, cosmetics, adhesives, biocides, disinfectants, printed paper etc. (Srivastava et al. 2004). The indoor levels observed in school C may reflect inefficient ventilation conditions (windows and doors were always closed), and cooking activities in the same building as the classrooms. School E presented the highest levels of both aliphatic hydrocarbons and esters in comparison with other schools, probably due to the fact that the building had recently been painted. The highest aromatic hydrocarbon concentrations were observed at school K, likely due to its location in a street canyon with intense traffic.

Among all monitored VOCs, benzene, toluene, ethylbenzene and xylenes (BTEX) are of particular interest due to their known carcinogenic effects (Kotzias et al. 2009). Indoor and outdoor BTEX concentrations are summarised in Table 4. Benzene concentrations were higher for all indoor environments, ranging from 0.2 to a maximum of 0.9 μg/m^3. All measurements were below the EU limit value of

Table 3 Indoor and outdoor VOC and carbonyl concentrations (μg/m^3) in all schools

			Aliphatic hydrocarbons	Aldehydes and ketones	Ethers and alcohols	Aromatic hydrocarbons	Terpenes	Esters	Halogenated hydrocarbons	Others
School A	Indoor	I	3.77	7.96	18.2	4.95	0.24	9.38		0.55
		II	5.55	15.0	25.7	6.35	0.75	11.1	–	9.16
	Outdoor		3.83	4.55	52.0	17.6	2.91	3.16	–	0.75
School B	Indoor	I	4.12	12.8	28.3	5.90	3.11	20.9	–	2.98
		II	5.58	31.2	31.2	9.04			–	
	Outdoor		2.11	3.67	17.9	3.36	4.64	29.1	–	0.94
School C	Indoor	I	8.43	29.7	36.9	12.6	7.50	27.0	–	0.86
		II	8.04	17.2	27.8	10.2	5.19	13.2	–	1.14
	Outdoor		3.72	4.18	20.0	4.56	0.31	–	–	–
School D	Indoor	I	6.51	18.1	29.4	6.71	7.51	25.3	–	1.15
		II	6.00	10.0	23.9	3.96	2.80	3.51	–	4.55
	Outdoor		2.11	3.34	16.0	2.85	0.55	–	–	0.36
School E	Indoor	I	18.5	32.3	47.7	17.5	7.88	38.7	–	7.13
		II	43.6	29.5	79.7	27.6	13.3	79.1	0.12	19.0
	Outdoor		2.99	17.6	18.3	4.7	0.22	1.88	–	0.26
School F	Indoor	I	3.94	22.5	245	4.04	4.63	8.83	–	10.8
		II	3.11	26.2	29.8	3.65	4.37	59.3	–	0.35
	Outdoor		2.31	3.18	16.8	3.38	0.16	–	–	–
School G	Indoor	I	16.4	53.6	48.3	46.5	10.2	12.9	0.41	57.9
		II	6.97	24.8	60.3	14.4	6.5	18.5	–	3.20
	Outdoor		2.94	3.24	26.5	4.21	0.56	0.71	–	0.23
School H	Indoor	I	5.55	33.1	25.5	6.35	40.3	13.8	–	0.61
		II	3.33	29.2	17.6	5.10	28.3	18.6	–	0.33
	Outdoor		2.51	5.20	–	3.21	0.29	–	–	0.12
School I	Indoor	I	5.55	33.7	8.69	19.0	4.69	37.9	–	4.54
		II	4.56	25.8	15.6	10.8	4.19	38.7	–	3.04
	Outdoor		2.48	4.10	20.4	4.02	0.49	0.37	–	0.20
School J	Indoor	I	2.72	15.2	44.4	5.56	9.87	8.55	–	3.85
		II	3.69	20.0	19.3	4.29	7.87	7.31	–	1.42
	Outdoor		1.51	2.95	11.7	2.24	0.12	–	–	–
School K	Indoor	I	4.36	21.2	40.2	8.06	9.27	27.7	–	1.09
		II	20.7	19.3	127	69.9	4.18	17.8	–	77.5
	Outdoor		3.61	3.42	30.1	5.09	0.57	0.58	–	0.29
School L	Indoor	I	3.76	11.8	18.8	10.8	1.45	10.6	–	2.44
		II	5.41	11.1	21.3	9.84	2.55	10.8	–	1.03
	Outdoor		3.18	3.44	–	3.66	0.14	–	–	0.21
School M	Indoor	I	4.44	10.1	26.6	9.05	6.20	29.8	–	1.76
		II	2.40	17.5	–	3.55	4.52	4.54	–	0.11
	Outdoor		2.52	3.94	32.6	3.12	0.16	–	–	–

Table 3 continued

			Aliphatic hydrocarbons	Aldehydes and ketones	Ethers and alcohols	Aromatic hydrocarbons	Terpenes	Esters	Halogenated hydrocarbons	Others
School N	Indoor	I	3.15	22.4	33.0	9.04	2.43	21.1	–	0.45
		II	10.6	19.3	21.4	19.8	10.6	19.1	–	3.76
	Outdoor		2.45	2.91	23.4	3.69	–	–	–	–

–: not identified

Aliphatic hydrocarbons: pentane, 2,2-dimethylbutane, *n*-hexane, isooctane, *n*–heptane, octane, nonane, *n*-decane

Aldehydes and ketones: formaldehyde, acetone, 4-methyl-2-pentanone, acetaldehyde, propionaldehyde, benzaldehyde

Ethers and alcohols: methanol, ethanol, isopropanol, butanol, 2-ethoxyethanol, methylcyclohexanol

Aromatic hydrocarbons: benzene, ethylbenzene, *m*+*p*-xylene, styrene, *o*-xylene, naphthalene

Terpenes: α-pinene, (+)-sabinene, β-pinene, (+)-3-carene, γ-terpinene, isoprene, limonene, eucalyptol

Esters: methyl acetate, ethyl acetate, propyl acetate, *n*-butyl acetate

Halogenated hydrocarbons: dichloromethane, l,2-dichloropropane

Others: cyclohexane, methylcyclohexane

5 μg/m^3 for mean annual exposure to benzene. However, as it is a carcinogenic compound, the WHO has not yet established a guide or safe value (WHO 2000, 2005). Toluene is a ubiquitous indoor pollutant (Bruno et al. 2008). Its indoor concentrations were higher than the corresponding outdoor levels, ranging from 0.9 to 7.3 μg/m^3. Concentrations of ethylbenzene comprise values from 0.3 to 14.2 μg/m^3, whereas the xylene isomers, *m*+*p*-xylene and *o*-xylene, were in the ranges 0.6–40 and 0.2–13.5 μg/m^3, respectively. Results for BTEX in this study correlate well with those of Stranger et al. (2007), except for toluene. The high benzene and toluene concentrations observed in Lisbon are in the same range as those measured in schools of Oporto, Portugal (Madureira et al. 2009). Toluene levels were very similar to those found in schools of Curitiba, Brazil (Godoi 2009). The BTEX levels in schools of Lisbon are far below the weekly average concentrations in non-residential indoor environments, such as libraries, pharmacies, offices, gymnasiums, newspaper stands, copy centres, coffee shops etc. in Bari, Italy (Bruno et al. 2008). BTEX values were much lower than the WHO guidelines from 2000 and 2005 (260 μg/m^3 over 1 week for toluene, 4.8 mg/m^3 over 24 h for xylenes). However, some studies have correlated exposure to low concentrations of benzene and toluene with increased risks of cancer or eye and airway irritations (Guieysse et al. 2008).

The highest indoor VOC concentrations were found in schools E, F, G and K. A possible indoor source in schools E and K was the vinyl flooring and floor adhesives, which are described as emitter materials, especially of benzene, toluene, xylenes, styrene and ethylbenzene, among others (Mendell 2007). In addition to these indoor sources, the inadequate ventilation (closed windows) likely favours accumulation of pollutants. New furniture and/or the fact of being a new building could also explain the high levels in school E. The VOC loads in school G are possibly related to the proximity to congested motorways surrounding the city. School F is located close to an old cigarette factory, near motorways, in an area without green spaces and with urban planning deficit. These housing conditions may have contributed to the high concentrations of ethers and alcohols. Better ventilation conditions, lower occupancy density and larger classrooms in school A in relation to other institutions may explain the low indoor levels observed at that school.

At all locations, the indoor concentrations of atmospheric aldehydes (formaldehyde, acetaldehyde, propionaldehyde and benzaldehyde) were higher than those outdoors, particularly for formaldehyde (Fig. 5), which is classified as a human carcinogen by the International Agency for Cancer Research. Formaldehyde concentrations ranged from 1.48 to 42.3 μg/m^3. Higher levels in classrooms than outdoors suggest that indoor sources are more important contributors to the

Table 4 Overview of indoor and outdoor BTEX concentrations in 14 schools in Lisbon

			BTEX (μg/m^3)				
			Benzene	Toluene	Ethylbenzene	*m*+*p*-Xylene	*o*-Xylene
School A	Indoor	I	0.30	1.98	0.73	0.95	0.99
		II	0.29	2.20	0.84	1.78	1.25
	Outdoor		0.38	5.31	2.67	6.68	2.53
School B	Indoor	I	0.31	2.12	0.54	1.04	1.89
		II	0.34	6.45	0.73	0.70	0.82
	Outdoor		0.31	1.56	0.39	0.86	0.24
School C	Indoor	I	0.34	2.14	1.66	3.54	4.96
		II	0.33	1.96	1.39	3.04	3.45
	Outdoor		0.37	1.74	0.57	1.40	0.47
School D	Indoor	I	0.36	2.83	1.11	1.86	0.55
		II	0.28	1.99	0.33	0.87	0.34
	Outdoor		0.29	1.24	0.34	0.77	0.23
School E	Indoor	I	0.37	5.34	2.58	6.18	2.99
		II	0.29	7.31	4.37	9.38	5.42
	Outdoor		0.35	1.91	0.62	1.32	0.46
School F	Indoor	I	0.30	1.63	0.59	1.01	0.52
		II	0.22	1.45	0.50	0.92	0.56
	Outdoor		0.29	1.41	0.44	0.89	–
School G	Indoor	I	0.27	4.47	14.2	19.7	7.90
		II	0.28	2.91	1.58	3.28	6.38
	Outdoor		0.36	1.84	0.48	1.16	0.38
School H	Indoor	I	0.26	1.98	0.97	2.20	0.93
		II	0.23	1.81	0.73	1.70	0.63
	Outdoor		0.27	1.28	0.33	0.99	0.34
School I	Indoor	I	0.41	5.55	2.60	5.35	5.06
		II	0.41	3.21	1.17	2.39	3.60
	Outdoor		0.26	1.79	0.48	1.14	0.35
School J	Indoor	I	0.29	1.72	0.60	0.94	2.00
		II	0.32	1.59	0.29	0.92	0.56
	Outdoor		0.26	0.87	0.90	0.62	0.20
School K	Indoor	I	0.32	3.13	1.18	2.65	0.79
		II	0.49	2.61	14.0	40.0	9.71
	Outdoor		0.45	5.74	0.43	1.17	0.37
School L	Indoor	I	0.28	1.42	0.58	1.33	7.18
		II	0.31	5.5	0.48	1.15	2.40
	Outdoor		0.33	1.42	0.64	1.00	0.27
School M	Indoor	I	0.94	4.34	1.00	1.81	0.95
		II	0.28	1.47	0.47	0.96	0.36
	Outdoor		0.22	1.35	0.31	0.97	0.27
School N	Indoor	I	0.31	1.52	0.74	1.60	4.87
		II	0.28	2.01	1.22	2.80	13.5
	Outdoor		0.40	1.60	0.44	0.98	0.27

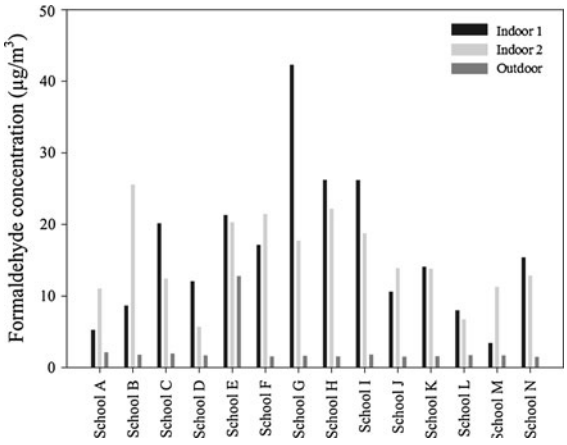

Fig. 5 Formaldehyde concentration in all schools

indoor levels than outdoor sources such as infiltration of vehicle exhaust (Ongwandee et al. 2009). Formaldehyde could originate from composite wood and other products with urea–formaldehyde resin, some architectural finishes, tobacco smoke and other combustion processes (Mendel 2007). Concentrations of formaldehyde are significantly affected by season and building age (Dingle and Franklin 2002). It was observed that levels are higher in the presence of furniture bought new or restored less than 1 year before measurements (Lovreglio et al. 2009). In spring and summer, outdoor formaldehyde levels increase due to acceleration of photochemical activity (Lee et al. 2001b), while the opposite trend is observed indoors, since the interchange rate between indoor and outdoor air is higher due to open windows or use of air conditioning (Pilidis et al. 2009). The highest level of formaldehyde was observed at school G. The high levels may be related to the fact that this institution is located in the vicinity of major motorways with very intense traffic. It should be also noted that the ceilings were painted during the Shrovetide period and new furniture was purchased just 1 month before the sampling campaign. In addition, the school corridors are wood coated. Pressed wood products use adhesive containing urea formaldehyde that can break down, releasing formaldehyde into the air. Formaldehyde is also found as a preservative in paint. Acute symptoms from formaldehyde exposure have sometimes been found, including eye, nose and throat irritation, as well as lower airway and pulmonary effects (Kotzias et al. 2009). Among the identified aldehydes, formaldehyde was the most abundant. However, other carbonyl compounds were also present at appreciable amounts: acetaldehyde (0.88–7.02 μg/m^3), propionaldehyde (0.48–2.28 μg/m^3) and benzaldehyde (0.03–0.96 μg/m^3).

Animal and human experimental studies indicate that NO_2 at short-term concentrations exceeding 200 μg/m^3 is a pollutant with significant health effects (Kraft et al. 2005). Exposure to NO_2 at hourly peak levels of the order of ≥80 ppb, compared with background levels of 20 ppb, was associated with a significant increase of sore throats, colds and absences from school (Pilotto et al. 1997). The average NO_2 concentrations were higher outdoors than indoors (Table 5), probably as a result of vehicular exhaust emissions from nearby traffic. The I/O NO_2 ratios ranged between 0.36 and 0.95. Indoor NO_2 levels were within the interval 15–37 μg/m^3, not exceeding the current WHO guideline value of 40 μg/m^3 (annual mean) to protect public health. School E, which presented an outdoor concentration of 42 μg/m^3, registered the lowest level of indoor NO_2 (15 μg/m^3), possibly because the windows and the doors were always closed. An average NO_2 concentration of 39 μg/m^3 was registered in classrooms in Taiyuann, China (Zhao et al. 2008). Levels varying from 9.5 to 23 μg/m^3 and from 11 to 19 μg/m^3 were obtained, respectively, in the indoor air and outside of elementary schools in Curitiba, Brazil (Godoi et al. 2009). Lee and Chang (2000) found indoor and outdoor NO_2 levels ranging from 12

Table 5 Indoor and outdoor NO_2 concentrations (μg/m^3)

	Indoor	STDEV	Outdoor	STDEV	I/O NO_2
School A	31.0	2.97	36.5	1.90	0.85
School B	35.2	11.2	37.2	2.85	0.95
School C	32.6	4.38	45.9	5.23	0.71
School D	33.3	3.26	39.4	2.87	0.85
School E	14.9	2.26	41.6	3.10	0.36
School F	33.5	1.95	35.7	16.9	0.94
School G	21.7	1.03	42.4	3.42	0.51
School H	34.0	3.67	37.5	4.63	0.91
School I	37.4	0.31	41.5	9.32	0.90
School J	20.2	8.22	25.1	9.22	0.81
School K	29.6	3.96	45.7	3.83	0.65
School L	32.2	2.22	39.1	4.76	0.82
School M	35.5	6.30	39.1	0.80	0.91
School N	30.7	5.35	35.9	1.82	0.85

to 176 μg/m^3 and 19 to 244 μg/m^3, respectively, for five classrooms at different schools in Hong Kong.

Conclusions

Indoor and outdoor concentrations of NO_2, VOCs, carbonyls and microbiological components, and comfort parameters [temperature, relative humidity, carbon dioxide (CO_2), carbon monoxide (CO) and total VOCs] were measured in 14 elementary schools in Lisbon. The concentration of CO_2 and bioaerosols greatly exceeded the AMV of 1,800 mg/m^3 and 500 CFU/m^3, respectively, perhaps due to overcrowded classrooms and inefficient ventilation. Schools located near streets with busy traffic presented the highest outdoor (45.7 μg/m^3) and lowest indoor (29.6 μg/m^3) NO_2 levels, possibly because the windows and the doors were always closed. Generally, the assessed VOCs occurred at I/O ratios above unity, showing the important influence of indoor sources and building conditions on IAQ. Most of the gaseous pollutants can be blamed on traffic emissions and indoor sources [some architectural finishes, floor adhesives, polyvinylchloride (PVC) flooring, consumer products and cleaning products]. Better ventilation should be provided for these public buildings, and air cleaners should be used to improve children's health, and their performance. More studies are needed (currently underway) to find additional possible sources of indoor contamination, to calculate air exchange rates on a seasonal basis, to evaluate if there is a causal relationship between pollutant exposure and health symptoms in schools and to assess if school IAQ can adversely affect academic performance or attendance.

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References

ANSI/ASHRAE Standard 62-1999. (1999). *Ventilation for acceptable indoor air quality*, Atlanta: American society of heating, refrigerating, and air-conditioning engineers, Inc.

ANSI/ASHRAE Standard 55–2004. (2004). *Thermal environmental conditions for human occupancy,* American society of heating, refrigerating and air-conditioning engineers, Inc. Atlanta, GA.

Bhugwant, C., & Hoareau, J. (2003). Variability of NO_2 in different environments at a moderately polluted island over the southwestern Indian Ocean. *Atmospheric Research, 66*, 241.

Blondeau, P., Iordache, V., Poupard, O., Genin, D., & Allard, F. (2005). Relationship between outdoor and indoor air quality in eight French schools. *Indoor Air, 15*, 2–12.

Borrego, C., Tchepel, O., Barros, N., & Miranda, A. I. (2000). Impact of road traffic emissions on air quality of the Lisbon region. *Atmospheric Environment, 34*, 4683–4690.

Bruno, P., Caselli, M., de Gennaro, G., Iacobellis, S., & Tutino, M. (2008). Monitoring of volatile organic compounds in non-residential indoor environments. *Indoor Air, 18*, 250–256.

Chaloulakou, A., Mavroidis, I., & Duci, A. (2003). Indoor and outdoor carbon monoxide concentration relationships at different microenvironments in the Athens area. *Chemosphere, 52*, 1007–1019.

Chew, G. L., Correa, J. C., & Perzanowski, M. S. (2005). Mouse and cockroach allergens in the dust and air in northeastern United States inner-city public high schools. *Indoor Air, 15*, 228–234.

Cocheo, V., Boaretto, C., & Sacco, P. (1996). High uptake rate radial diffusive sampler suitable for booth solvent an thermal desorption. *American Industrial Hygiene Association Journal, 57*, 897–904.

Daisey, J. M., Angell, W. J., & Apte, M. G. (2003). Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air, 13*, 53–64.

Dingle, P., & Franklin, P. (2002). Formaldehyde levels and the factors affecting these levels in homes in Perth, Western Australia. *Indoor and Built Environment, 11*, 111–116.

Finnigan, M. S., Pickering, C. A. C., & Burge, P. S. (1984). The sick building syndrome: Prevalence studies. *British Medical Journal, 289*, 1573–1575.

Fisk, W. J. (2001). Estimates of potential nationwide productivity and health benefits from better indoor environments: An update. In J. Spengler, J. M. Samet, & J. F. McCarthy (Eds.), *Indoor air quality handbook* (pp. 1–36). New York: McGraw Hill.

Godoi, R., Avigo, D., Jr, Campos, V., Tavares, T., de Marchi, M., Grieken, R., et al. (2009). Indoor air quality assessment of elementary schools in Curitiba, Brazil. *Water, Air, Soil Pollution, 9*, 171–177.

Godwin, C., & Batterman, S. (2007). Indoor air quality in Michigan schools. *Indoor Air, 17*, 109–121.

Gonçalves, F. L. T., Bauer, H., Cardoso, M. R. A., Pukinskas, S., Matos, D., Melhem, M., et al. (2010). Indoor and outdoor atmospheric fungal spores in the Sao Paulo metropolitan area (Brazil): Species and numeric concentrations. *International Journal of Biometeorology, 54*, 347–355.

Griffiths, M., & Eftekhari, M. (2008). Control of CO_2 in a naturally ventilated classroom. *Energy and Buildings, 40*, 556–560.

Guieysse, B., Hort, C., Platel, V., Munoz, R., Ondarts, M., & Revah, S. (2008). Biological treatment of indoor air for

VOC removal: Potential and challenges. *Biotechnology Advance, 26*(5), 398–410.

Hodgson, M. (1992). Field studies on the sick building syndrome. *Annals of the New York Academy of Sciences, 641*, 21–36.

Hodgson, A. T., Shendell, D. G., Fisk, W. J., & Spte, M. G. (2004). Comparison of predicted and derived measures of volatile organic compounds inside four new relocatable classrooms. *Indoor Air, 14*, 135–144.

Jo, W. K., & Seo, Y. J. (2005). Indoor and outdoor bioaerosol levels at recreation facilities, elementary schools, and homes. *Chemosphere, 61*, 1570–1579.

Jones, A. Y. M., & Lam, P. K. W. (2006). End-expiratory carbon monoxide levels in healthy subjects living in a densely populated urban environment. *Science of the Total Environment, 354*, 150–156.

Khan, I., Freitas, M. C., Dionísio, I., & Pacheco, A. (2007a). Particulate matter levels in Portugal (Mainland and Islands)—A preliminary study for outdoor/indoor environ ment in basic schools, *Proceedings of the Ninth REHVA World Congress Clima 2007 "WellBeing Indoors"*, Helsinki, Finland.

Khan, I., Freitas, M. C., & Pacheco, A. (2007b). Indoor habits of children aged 5–10 years learning at the public basic schools of Lisbon-City, Portugal, *Proceedings of the Ninth REHVA World Congress Clima 2007 "WellBeing Indoors"*, Helsinki, Finland.

Kim, J. L., Elfman, L., Mi, Y., Wieslander, G., Smedje, G., & Norbäck, D. (2007). Indoor molds, bacteria, microbial volatile organic compounds and plasticizers in schools–associations with asthma and respiratory symptoms in pupils. *Indoor Air, 17*, 153–163.

Klinmalee, A., Srimongkol, K., & Oanh, N. T. K. (2009). Indoor air pollution levels in public buildings in Thailand and exposure assessment. *Environment Monitoring Assessment, 156*, 581–594.

Kotzias, D., Geiss, O., Tirendi, S., Barrero-Moreno, J., Reina, V., & Gotti, A. (2009). Exposure to multiple air contaminants in public buildings, schools and kindergartens—the European indoor air monitoring and exposure assessment (AIRMEX) study. *Fresenius Environmental Bulletin, 18*(5a), 670–681.

Kotzias, D., Koistinen, K., Kephalopoulos, S., Schlitt, C., Carrer, P., Maroni, M., et al. (2005). The INDEX project: Critical appraisal of the setting and implementation of indoor exposure limits in the EU. Final Report, EUR 21590 EN.

Kraft, M., Eikmann, T., Kappos, A., Künzli, N., Rapp, R., Schneider, K., et al. (2005). The German view: Effects of nitrogen dioxide on human health—derivation of health-related short-term and long-term values. *International Journal of Hygiene and Environmental Health, 208*, 305–318.

Lee, S. C., & Chang, M. (2000). Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere, 41*, 109–113.

Lee, S. C., Ho, K. F., Chan, L. Y., Zielinska, B., & Chow, J. C. (2001a). Polycyclic aromatic hydrocarbons (PAHs) and carbonyl compounds in urban atmosphere of Hong Kong. *Atmospheric Environment, 35*, 5949–5960.

Lee, S. C., Li, W. M., & Chan, L. Y. (2001b). Indoor air quality at restaurants with different styles of cooking in metropolitan Hong Kong. *Science of the Total Environment, 279*, 181–193.

Lee, S. C., Guo, H., Li, W. M., & Chan, L. Y. (2002a). Intercomparison of air pollutant concentrations in different indoor environment in Hong Kong. *Atmospheric Environment, 36*, 1929–1940.

Lee, S. C., Li, W. M., & Ao, C. H. (2002b). Investigation of indoor air quality at residential homes in Hong Kong—case study. *Atmospheric Environment, 36*, 225–237.

Li, W. M., Lee, S. C., & Chan, L. Y. (2001). Indoor air quality at nine shopping malls in Hong Kong. *Science of the Total Environment, 273*, 27–40.

Lovreglio, P., Carrus, A., Iavicoli, S., Drago, I., Persechino, B., & Soleo, L. (2009). Indoor formaldehyde and acetaldehyde levels in the province of Bari, South Italy, and estimated health risk. *Journal of Environmental Monitoring, 11*, 955–961.

Madureira, J., Alvim-Ferraz, M. C. M., Rodrigues, S., Gonçalves, C., Azevedo, M. C., Pinto, E., et al. (2009). Indoor air quality in schools and health symptoms among Portuguese teacher. *Human and Ecological Risk Assessment, 15*, 159–169.

May, K., & Harper, G. (1957). The efficiency of various liquid impinger samplersin bacterial aerosols. *Journal of Industrial Medical, 14*, 287.

Meklin, T., Husman, T., Vepsäläinen, A., Vahteristo, M., Koivisto, J., Halla-Aho, J., et al. (2002). Indoor air microbes and respiratory symptoms of children on moisture damaged and reference schools. *Indoor Air, 12*, 175–183.

Mendell, M. J. (2007). Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: A review. *Indoor Air, 17*, 259–277.

Mentese, S., Arisoy, M., Rad, A. Y., & Güllü, G. (2009). Bacteria and fungi levels in various indoor and outdoor environments in Ankara, Turkey. *Clean-Soil, Air Water, 37*, 487–493.

Mines, M. D. (1997). The heme oxygenase system: A regulator of second messenger gases. *Annual Review Pharmacology and Toxicology, 37*, 517–554.

Mishra, S. K., Ajello, L., Ahearn, D. G., Burge, H. A., Kurup, B. P., Pierson, D. L., et al. (1992). Environmental mycology and its importance to public health. *Journal of Medical and Veterinary Mycology, 30*, 287–305.

Mukerjee, S., Smith, L. A., Johnson, M. M., Neas, L. M., & Stallings, C. A. (2009). Spatial analysis and lan use regression of VOCs and NO_2 from school-based urban air monitoring in Detroit/Dearbon, USA. *Science of the Total Environment, 407*, 4646–4651.

Ongwandee, M., Moonrinta, R., Panyametheekul, S., Tangbanluekal, C., & Morrison, G. (2009). Concentrations and strengths of formaldehyde and acetaldehyde in office buildings in Bangkok, Thailand. *Indoor and Built Environment, 18*, 569–575.

Ott, W. R., Steinemann, A. C., & Wallace, L. A. (2007) *Exposure analysis*. New York: CRC Taylor and Francis Group. ISBN 1 56670 663 7.

Pegas, P. N., Evtyugina, M. G., Alves, C. A., Nunes, T., Cerqueira, M., Franchi, M., et al. (2009), Outdoor/indoor air quality in primary schools in Lisbon: a preliminary study, *Proceedings of the 11th International Conference on Environmental Science and Technology*, Chania, Crete, Greece.

Pegas, P. N., Evtyugina, M. G., Alves, C. A., Nunes, T., Cerqueira, M., Franchi, M., et al. (2010). Outdoor/Indoor air quality in primary schools in Lisbon: A preliminary study. *Química Nova, 33*, 1145–1149.

Pilidis, G. A., Karakitsios, S. P., Kassomenos, P. A., Kazos, E. A., & Stalikas, C. D. (2009). Measurements of benzene and formaldehyde in a medium sized urban environment. Indoor/outdoor health risk implications on special population groups. *Environmental Monitoring and Assessment, 150*, 285–294.

Pilotto, L. S., Douglas, R. M., Attewell, R. G., & Wilson, S. R. (1997). Respiratory effects associated with indoor nitrogen dioxide exposure in children. *International Journal of Epidemiology, 26*, 788–796.

Plácido, J. L. (2004). A asma a nível nacional e mundial: perspectivas actuais e tendências de evolução. *Revista Portuguesa de Clínica Geral, 20*, 583–587.

RSECE (2006). Decreto-Lei n.° 79/2006—Regulamento dos Sistemas Energéticos de Climatização em Edifícios (RSECE), de 04/04/2006, Ministério das Obras Públicas, Transportes e Comunicações.

Scheff, P., Paulius, V., Curtis, L., & Conroy, L. (2000), Indoor air quality in middle school., Part II: development of emission factors for particulate matter and bioaerosols, *Applied Occupational and Environmental Hygiene* 43, 298.

Shendell, D. G., Winer, A. M., Weker, R., & Colome, S. D. (2004). Evidence of inadequate ventilation in portable classrooms: results of pilot study in Los Angeles County. *Indoor Air, 14*, 154–158.

Singer, B. C., Destaillats, H., Hodgson, A. T., & Nazaroff, W. W. (2006). Cleaning products and air fresheners: emissions and resulting concentrations of glycol ethers and terpenoids. *Indoor Air, 16*, 179–191.

Sohn, J., Yang Kim, J., Son, B., & Park, J. (2009). Indoor air quality investigation according to age of the school buildings in Korea. *Journal of Environmental Management, 90*, 348–354.

Spangler, J. D., & Sexton, K. (1983). Indoor air pollution: A public health perspective. *Science, 221*, 9–17.

Srivastava, A., Joseph, A. E., & Wachasunder, S. D. (2004). Qualitative detection of volatile organic compounds in outdoor and indoor air. *Environmental Monitoring and Assessment, 96*, 263–271.

Stranger, M., Potgieter-Vermaak, S. S., & Van Grieken, R. (2007). Comparative overview of indoor air quality in Antwerp, Belgium. *Environment International, 33*, 789–797.

Stranger, M., Potgieter-Vermaak, S. S., & Van Grieken, R. (2008). Characterization of indoor air quality in primary schools in Antwerp, Belgium. *Indoor Air, 18*, 454–463.

WHO. (2000). Air quality guidelines for Europe. 2nd ed. Copenhagen, World Health Organization Regional Office for Europe, 2000 (WHO Regional Publications, European Series no. 91).

WHO. (2005). Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide *Global update 2005* Summary of risk assessment. World Health Organization 2006.

Witterseh, T., Wyon, D. P., & Clausen, G. (2004). The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work. *Indoor Air, 14*(8), 30–40.

Yrieix, C., Dulaurent, A., Laffargue, C., Maupetit, F., Pacary, T., & Uhde, E. (2010). Characterization of VOC and formaldehyde emissions from a wood based panel: Results from an inter-laboratory comparison. *Chemosphere* (in press).

Zayasu, K., Sekizawa, K., Okinaga, S., Yamaya, M., Ohrui, T., & Sasaki, H. (1997). Increased carbon monoxide in exhaled air of asthmatic patiens. *American Journal Respiratory and Critical Care Medicine, 156*, 1140–1143.

Zhang, G., Spickett, J., Rumchev, K., Lee, A., & Stick, S. (2006). Indoor environmental quality in a "low allergen" school and three standard primary schools in Western Australia. *Indoor Air, 16*, 74–80.

Zhao, Z., Zhang, Z., Wang, Z., Ferm, M., Liang, Y., & Norbäck, D. (2008). Asthmatic symptoms among pupils in relation to winter indoor and outdoor air pollution in schools in Taiyuan, China. *Environmental Health Perspectives, 116*, 90–97.