DEVELOPING METHODOLOGY FOR EXPOSURE ASSESSMENT OF AIR POLLUTANTS IN SCHOOLS

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by

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Abstract

Increasing evidence suggests that exposures to air pollutants present in indoor environments are contributing factors to the recently observed increase in respiratory symptoms among young children. The SchoolAir pilot study aimed to assess the hypothesis that poor indoor and outdoor air quality in schools is associated with increased prevalence of asthma, respiratory and allergic symptoms among primary school children, and assess the feasibility of a bigger full-scale research project in the future. The main aim of this MPhil project was to develop and test a methodology for exposure assessment of indoor and outdoor pollutants in primary schools. A secondary aim was to assess the prevalence rate or respiratory symptoms and their relationship to air pollutant exposure in different schools.

The following pollutants were measured indoors and outdoors: carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), total volatile organic compounds (TVOC) formaldehyde (HCHO), and particulate matter of 0.5–5.0 micrometers in diameter ($PM_{0.5\text{-}5.0}$). A questionnaire was used to assess respiratory health effects in children. Air quality monitoring was conducted in three rounds in four primary schools in England. Real time measurements were performed simultaneously in three indoor locations and one outdoor location within each school, for one week during usual school hours. Personal exposure (PE) to each pollutant was estimated combining time-activity patterns of children and measured concentrations.

Findings showed important temporal and spatial variations in concentrations of certain air components. The most prominent variability was observed for $PM_{0.5\text{-}5.0}$ and CO_2. Weekly means for PE to $PM_{0.5\text{-}5.0}$, NO_2 and TVOC were higher than concentrations measured in classrooms (ME) in the majority of cases, whereas for CO, HCHO and CO_2 the opposite effect was observed.

The calculated coefficients of variations for ME and PE revealed that variability of modelled PE was higher than that of relevant ME. Thus modelled PE seems to reflect more of the actual variability of exposures that children had during their days at school than exposures measured by fixed monitors in a classroom. The results of linear regression of PE to ME showed that for the three of the six investigated indoor air components – $PM_{0.5\text{-}5.0}$, NO_2, and CO_2 – less than 50% of the variation of PE could be explained by the variation of relevant ME. For the other three pollutants – CO, HCHO and TVOC the results of linear regression were inconclusive, as half of the calculated coefficients of determinations (R^2) were above 0.5 and the other half were below 0.5.

Preliminary analysis of the health survey results revealed variations of respiratory and allergic symptoms prevalence between the investigated schools. It was shown that the children in one of the suburban schools, where the modelled yearly mean PEs were in the upper end of the inter-school yearly means range had the highest proportion of respiratory and allergic symptoms, whereas in the rural school the modelled yearly mean PEs were overall in the lower end of the inter-school yearly means range, and the children of the rural school had the lowest prevalence of symptoms.

The methodology used in this study for the assessment of children's personal exposure to air pollutants during a school day employed a combination of measurements by stationary monitors in school microenvironments and children's time-activity-location patterns. This study revealed important differences between concentrations measured with fixed monitors and estimated personal exposures for all measured pollutants. This methodology is efficient and potentially less expensive than individual personal monitoring.

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Abbreviations

CL	Confidence Limit
COMEAP	Committee on the Medical Effects of Air Pollutants (Department of Health, UK)
CV	Coefficient of Variation
EPA	Environmental Protection Agency (USA)
FEV_1	Forced Expiratory Volume in 1 second
GM	Geometric Mean
GSD	Geometric Standard Deviation
IAP	Indoor Air Pollution
ISAAC	International Study of Asthma and Allergies in Childhood
ME	Measured Exposure (with a fixed monitor)
MPhil	Master of Philosophy
NIOSH	National Institute for Occupational Safety and Health (USA)
OR	Odds Ratio
OSHA	Occupational Safety and Health Administration (USA)
p	P-value
PE	Personal Exposure (modelled)
PM	Particulate Matter
$PM_{0.5\text{-}5.0}$	Particulate Matter with aerodynamic diameter of 0.5-5.0 μm
PTEAM	Particle Total Exposure Assessment Methodology
R	Correlation Coefficient
R^2	Coefficient of Determination
SD	Standard Deviation
SEM	Scanning Electron Microscope
TEAM	Total Exposure Assessment Methodology
TVOC	Total Volatile Organic Compounds
VOC(s)	Volatile Organic Compound(s)
WHO	World Health Organisation

Pollutants investigated in the SchoolAir pilot study

CO	Carbon monoxide
CO_2	Carbon dioxide
HCHO	Formaldehyde
NO_2	Nitrogen dioxide
$PM_{0.5\text{-}5.0}$	Particulate matter with aerodynamic diameter of 0.5-5.0 μm
TVOC	Total volatile organic compounds

1. Introduction

The increase in prevalence of asthma and allergic respiratory symptoms and diseases and allergies among children is becoming of considerable concern (ISAAC Steering Committee, 1998; Pearce *et al.*, 2007). In the UK, prevalence of these conditions is amongst the highest in the world (Austin *et al.*, 1999; Pearce *et al.*, 2007). Environmental exposures to air pollutants are shown to be associated with increased respiratory sensitisation and reduced lung function (Brunekreef *et al.*, 1997; Annesi-Maesano *et al.*, 2007).

In Britain air pollution has been a long time problem. In the 13th century London suffered from smoke pollution caused by coal burning resulting in the first air pollution law being passed in order to reduce the nuisance from smoke caused by domestic fires. During the industrial revolution of the 19th century serious air pollution was caused by the growing industries, and as a response a series of Smoke Abatement Acts and Alkali Act which aimed to control acid emissions from alkali works were passed in mid-19th century (Woodin, 1989).

Following the great smog event that happened in London, UK, in 1952, which caused an estimated excess death toll of over 4,000, great public and scientific attention was drawn to the effects of air pollution on human health (Brunekreef and Holgate, 2002). As a result, the Clean Air Act was passed in 1956, which established smoke control areas in British cities (Woodin, 1989).

A new era of air pollution and health studies started in 1970-1980 when two cohort studies were conducted in the USA, which suggested that exposure to fine particulate matter in the air was associated with life shortening effects (Brunekreef and Holgate, 2002). Studies investigating the effects of ambient air pollution were undertaken and several associations with adverse health were established (Hoek *et al.*, 1990; Dockery *et al.*, 1993; He *et al.*, 1993; Jones *et al.*, 1994; Pope *et al.*, 1995; Peters *et al.*, 1996; Asgari *et al.*, 1998; Chen *et al.*, 1999; Schwartz, 2004; Annesi-Maesano *et al.*, 2007).

Indoor air pollution (IAP) is becoming an important issue in the recent decade due to its contribution to the global burden of disease. It has been estimated by the World Health Organization, that 1.6 million premature deaths are caused annually due to IAP in developing countries, where women and children are more vulnerable because of their daily routines, such as cooking and the use of solid fuels (WHO, 2002).

Children are more susceptible to air pollutants than adults due to ongoing biological development of their immune and respiratory systems (Schwartz, 2004; Buka *et al.*, 2006) and higher metabolic rate, which results in more breaths per minute and increases the exposure of the airway per unit time (Kulkarni and Grigg, 2008). The lung is not well formed at birth and development of full functionality does not occur until approximately 6 years of age. Children also have a larger lung surface area per kilogram of body weight than adults and breathe 50% more air per kilogram of body weight than adults (Schwartz, 2004; Belanger *et al.*, 2006; Liu *et al.*, 2009). Thus childhood is a critical exposure time when air pollution may have significant and lasting effects on the respiratory health. It has been noted that exposure to air pollutants during prenatal development or at young age increases the risk of chronic illness and death later in life (Schwartz, 2004).

Recently, an important increase in the prevalence of asthma, respiratory symptoms and allergies has been noticed among young children, in particular in developed countries (Pearce *et al.*, 1993; ISAAC Steering Committee, 1998; Austin *et al.*, 1999; Pearce *et al.*, 2007). Although these respiratory and allergic illnesses are of great public concern, it is not yet fully understood what causes these conditions. The current state of knowledge does not permit precision about the importance of genetic and environmental factors in development of asthmatic and allergic conditions, however there is evidence that air pollution such as sulphur dioxide, ozone, nitrogen oxides, occupational dust, organic and inorganic suspended particulate matter, tobacco smoke, etc., can cause an increase in airway reactivity through mechanisms dependent on or independent of specific IgE antibodies (Obtulowicz, 1993). One potential mechanism of action of air pollutants on the respiratory system is through enhancement of airway inflammation (Delfino, 2002).

A number of epidemiological studies have examined a possible correlation between IAP as potential triggers of childhood respiratory illness and aimed to measure indoor pollutant levels and establish the relationship between exposure and adverse health effects in children (Norback *et al.*, 1990; Pilotto *et al.*, 2004; Zhang *et al.*, 2006; Hansel *et al.*, 2008; Liu *et al.*, 2009). Health outcomes were often established by submitted questionnaires, and in some cases interviews or personal biomarker measurements were used (Zhang *et al.*, 2006; Kattan *et al.*, 2007; Epton *et al.*, 2008; Hansel *et al.*, 2008; Liu *et al.*, 2009).

Environmental factors that have been identified as risk factors for asthma morbidity and respiratory symptoms in children include particulate matter (PM) (Belanger *et al.*, 2006; Liu *et al.*, 2009) and gaseous pollutants such as nitrogen dioxide (NO_2) (Pilotto *et al.*, 2004; Belanger *et al.*, 2006; Mi *et al.*, 2006; Khalequzzaman *et al.*, 2007; Zhao *et al.*,

2008; Liu *et al.*, 2009), sulphur dioxide (SO_2) (Zhang *et al.*, 2006; Liu *et al.*, 2009), ozone (O_3) (Mi *et al.*, 2006; Zhao *et al.*, 2008), total volatile organic compounds (TVOC) (Adgate *et al.*, 2004; Khalequzzaman *et al.*, 2007), formaldehyde (HCHO) (Mi *et al.*, 2006; Zhao *et al.*, 2008), carbon dioxide (CO_2) (Mi *et al.*, 2006; Khalequzzaman *et al.*, 2007), and allergens such as pollen, dust mites and allergens of animal origin (Daisey *et al.*, 2003; Salo *et al.*, 2004; Breysse *et al.*, 2005; Zhang *et al.*, 2006). These air components are frequently found in the indoor environment, and may be either generated indoors or have an outdoor origin. In the case of IAP it is considered that it is not only ambient air that influences the indoor concentration levels, but also the presence of physical activity, building type, occupancy levels, as well as sources of outdoor origin (Blondeau *et al.*, 2005; Diapouli *et al.*, 2008; Stranger *et al.*, 2008; Heudorf *et al.*, 2009).

1.1. Methods of personal exposure estimation

The term "human exposure" was introduced by Ott in 1982. It was defined as "*an event that occurs when a person comes in contact with the pollutant"* (Ott, 1982). A comprehensive exposure assessment is a part of a risk assessment that evaluates the relationship between the source of a pollutant and its health effect.

Although an extensive research in the area of air pollution has been carried out, there are limitations in methods and study designs which result in gaps in available burden of evidence. Earlier studies that have assessed the effects of environmental pollutants on children's health have relied on questionnaires to ascertain both exposure and symptoms, making it difficult to exclude responder bias as the explanation for the associations (Dekker *et al.*, 1991; Duhme *et al.*, 1996). Later studies have relied on more objective measurements of exposure and disease, findings of which have also corroborated evidence for an association between ambient air pollution and respiratory symptoms in children (Brunekreef *et al.*, 1997; Janssen *et al.*, 2003). However, monitored ambient concentrations of air pollutants are not representative of personal exposures, which are important when evaluating the relation of exposure and health outcomes at the individual level. Data collected at central monitoring stations can provide only a general idea of the pollution in schools, but due to the small-area variations in pollution levels (within the school), they have very low accuracy (Mejía *et al.*, 2011). Only a limited number of studies have used quantitative exposure measurements of air pollutants to approximate individual exposure in children, either at residential address (Keeler *et al.*, 2002; Jaakkola *et al.*, 2004; Kattan *et al.*, 2007; Khalequzzaman *et al.*, 2007; Hansel *et al.*, 2008; Jerrett *et al.*, 2008; Liu *et al.*, 2009; McCormack *et al.*, 2009) or in schools (Keeler *et al.*, 2002; Pilotto *et al.*, 2004; Mi *et al.*, 2006; Zhang *et al.*, 2006; Epton *et al.*, 2008). It is worth noting that most of the studies

to date have also lacked the use of a more integrated approach of understanding the contribution of several microenvironments and several air pollutants to the observed health effects in children.

Personal exposure measurements can be performed directly and indirectly. In the direct approach exposure levels are determined on an individual (by using a personal sampler or a biomarker), whereas in the indirect approach exposure levels are either measured stationarily (ambient measurements or measurements of microenvironments) or determined by models (Ott, 1982; Monn, 2001).

The increase of interest in indoor environment arose from the fact that humans and children in particular spend large amount of time indoors (Silvers *et al.*, 1994; Klepeis *et al.*, 2001; Leickly, 2003). Recent studies have shown that children spent an average of 25%-30% of their time at school, 65% inside at home and overall they spent over 90% of their time indoors at any location (U.S. EPA, 2002; Adgate *et al.*, 2004). While it is ethically more difficult to measure and improve home environments, as well as less efficient in terms of reducing exposure of a target population, schools are easier to access and to improve indoor air quality on a bigger scale. Therefore improved measurements, remediation and risk reduction related to environmental exposures may be easier to achieve in schools than in domestic environments. Nevertheless, as of today there are only a handful of studies that investigated both indoor air quality in schools and the health effects in children attending these schools (Pilotto *et al.*, 2004; Mi *et al.*, 2006; Epton *et al.*, 2008; Zhao *et al.*, 2008).

A number of studies have shown that there are small-area variations in concentration levels of air pollutants (Monn, 2001; Hoek *et al.*, 2008; Guo *et al.*, 2010) and since children move around during their school hours the level of exposure varies according to their activities. Thus to accurately access children's exposure it is necessary to obtain detailed information about their daily activities (Mejía *et al.*, 2011).

Recently there has been increased scientific interest in interaction of various pollutants and multiple exposures. Investigators have begun to measure multiple pollutants present within the same environment, including particles, combustion products, NO_2, TVOC and allergens, as health effects are often related to multiple exposures (Mitchell *et al.*, 2007). For example, many epidemiological studies have used NO_2 as a marker of combustion related pollution mixtures (e.g. traffic exhausts and indoor combustion sources mixtures).

Thus health effects observed in these studies might also have been associated with other combustion products, such as particles, NO, or benzene (Morawska, 2010).

1.2. Study aims

The *overall aim* of the SchoolAir pilot study was to assess the hypothesis that poor indoor and outdoor air quality in schools is associated with increased prevalence of asthma, respiratory and allergic symptoms among primary school children, and assess the feasibility of a bigger full-scale research project in the future.

The study is unique in the way that many factors were considered simultaneously including air components and parameters (five gaseous components: carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), total volatile organic compounds (TVOC) and formaldehyde (HCHO); airborne particulate matter (PM), temperature, and humidity), as well as assessing personal exposure and respiratory health effects in children. In addition, several other groups of factors were assessed using the questionnaire – such as socio-economic status of children's families, their environmental exposures at home or in a local neighbourhood.

The *primary aim* of this Master of Philosophy (MPhil) project (within the overall pilot study) was to develop and test a methodology of personal exposure assessment to model personal exposures of children to air pollutants by combining measurements in several locations within a school (indoors and outdoors). It is envisaged that the developed methodology could be used for studies investigating health effects in children and adults in relation to air pollution.

The specific *secondary aims* of this MPhil project are listed below.

1) <u>Exposure assessment aims</u>:
    a) To assess the variability of measured air components' concentrations (within one school, between schools and seasonal variability).
    b) To compare the measured exposures with relevant modelled personal exposures and assess the differences between the schools and across the seasons.
2) <u>Health assessment aim</u>: To assess prevalence rate of respiratory and allergic symptoms in different schools.

1.3. Sources and health effects of selected pollutants

A subset of important indoor air pollutants was selected to be investigated under the SchoolAir pilot study. These are reviewed in this section including their sources and effects on human and, in particular, children's health.

1.3.1. Particulate matter (PM)

In the last two decades there has been an increased scientific interest and attention paid to airborne particles. Particulate matter (PM) is harder to characterise than many other air pollutants due to its multi-factorial nature. There are many physical, chemical and microbiological characteristics of PM that may be considered. The most important physical properties that can be considered when investigating health related effects are size (as airborne PM range in size from 0.001 µm to 100 µm), number concentration, number size distribution, mass concentration, mass size distribution, surface area, shape, electrical charge and light scattering properties (Morawska, 2010).

Particles can originate from both outdoor and indoor sources. Outdoor sources include motor vehicular emissions, industrial processes, power stations, waste disposal, fires and road dust (Bascom, 1996; Choi, 2011), however, Kappos *et al.* argue that combustion engines are the principal particle source in urban environment (Kappos *et al.*, 2004). Indoor combustion sources of particles include cooking, fireplaces, kerosene heaters and cigarette smoking. Also particles can be emitted from consumer products and building materials (U.S. EPA, 1994; Guo *et al.*, 2010), as well as produced or re-suspended by such non-combustion indoors sources as cleaning activities and movement of people (Abt *et al.*, 2000).

The size of airborne particles in the respiratory tract during inhalation is the most important property, determining the deposition probability (Londahl *et al.*, 2009). According to Owen *et al.* particles larger than 30 µm in aerodynamic diameter have low probability of entering the nasal passages. Particles of 5-10 µm in diameter usually deposit in the passages of the nose and pharyngeal region. Smaller particles (1-5 µm) deposit in the tracheal bronchiolar region, whereas particles less than 1 µm in diameter are deposited on alveolar walls by diffusion. Particles deposited in the alveoli require more mechanisms for removal than particles that deposit in the upper respiratory tract, thus they tend to remain longer and can cause more damage to the cells and the human body as a whole (Owen *et al.*, 1992). The smaller the particles the higher is the alveolar uptake: alveolar deposition of particles of 0.05 µm in diameter is about 40% in comparison with about 10% for 0.7 µm particles (Maynard, 2000).

However, the dose to the lungs depends not only on the deposition but also on particle persistence in the respiratory tract. Soluble particles (for example, particles from efficient combustion) are quickly dissolved, diluted and removed by circulation. Hydrophobic and insoluble particles (e.g. organic compounds and soot resulted from low temperature combustion) can persist in the lungs for a long time, especially if deposited in nonciliated alveolar region (Londahl *et al.*, 2008). Coarse particles (> 2.5 µm) are mainly formed by mechanical processes and fine (< 2.5 µm) and ultrafine (< 0.1 µm) are directly emitted (e.g. diesel soot) and formed by chemical reactions from gaseous precursors (Hoek *et al.*, 2008).

Some authors argued that $PM_{2.5}$ (particles with aerodynamic diameter under 2.5 µm) might better describe the component of particulate matter responsible for adverse effects since this smaller size fraction is capable of penetrating to the alveolar region of the respiratory system with far greater efficiency than coarse particles. It was also argued that fine particles are more toxic than coarse particles (Harrison and Yin, 2000). A number of authors stated that the number of ultrafine particles (UFP) is a more relevant exposure variable than the mass of particles, as UFP have a large surface area and can penetrate into the interstitium and into the blood stream (Seaton *et al.*, 1995; Wittmaack, 2007; Guo *et al.*, 2010; Morawska, 2010).

Studies conducted in the recent decade shown that the most significant health effects from inhalation of PM include decreased lung function, increased respiratory symptoms, chronic obstructive pulmonary disease, increased cardiovascular and cardiopulmonary disease, and increased mortality (Morawska, 2010). In their article Kulrarni and Grigg summarised the respiratory effects of particle pollution on children as the following: cough, asthma exacerbations and deficit in lung function. The authors also noted that daily fluctuations of PM_{10} were associated with acute respiratory hospital admissions in children, absences from school and kindergarten and increased use of asthma medication (Kulkarni and Grigg, 2008).

1.3.2. Carbon monoxide (CO)

Carbon monoxide is a product of incomplete combustion. It has low chemical reactivity and thus it is inert in the context of residence time in the indoor atmosphere (Harrison *et al.*, 2002). According to the Occupational Safety and Health Administration (OSHA, USA) indoor sources of carbon monoxide include the following: unvented kerosene and gas space heaters, leaking chimneys and furnaces, back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces, gas stoves, generators and other gasoline powered

equipment, automobile exhaust from attached garages, and tobacco smoke. Incomplete oxidation during combustion in gas ranges and unvented gas or kerosene heaters may cause high concentrations of CO in indoor air. Worn or poorly adjusted and maintained combustion devices (e.g., boilers, furnaces) can be significant sources (Croxford *et al.*, 2006; OSHA). These sources of CO are important in the UK, as here it is common for homes to have gas as the main fuel source for heating, hot water and cooking (Croxford *et al.*, 2005). Outdoor sources of CO include motor vehicles exhausts from nearby roads, parking areas or garages (OSHA).

CO is an asphyxiant. An accumulation of this odourless, colourless gas may result in a varied constellation of symptoms deriving from the compound's affinity for and combination with haemoglobin, forming carboxyhaemoglobin and disrupting oxygen transport. Inhaled CO rapidly diffuses across alveolar, capillary and placental membranes (U.S. EPA, 1994). Approximately 80-90% of the absorbed CO binds with haemoglobin to form carboxyhaemoglobin (Georgoulis *et al.*, 2002). The elderly, the foetus, and persons with cardiovascular and pulmonary diseases are particularly sensitive to elevated CO levels (U.S. EPA, 1994). Croxford *et al.* reported that people with chronic low level CO exposure frequently complain of difficulties in cognitive function and sometimes of emotional and physical difficulties (Croxford *et al.*, 2006). Results of a more recent UK study showed that households with at least one gas appliance (such as cooker, boiler, gas fire, or water heater) rated by authors as "at risk" or "immediately dangerous" reposted the presence of certain neurological symptoms more often than households without "at risk" or "immediately dangerous" appliances (Croxford *et al.*, 2008).

Results of a CO personal exposure study indicated that the effects of personal activity and indoor sources of CO greatly influenced personal exposures. The authors found that microenvironments associated with commuting, such as inside garages, inside a car or other motor transport, or near roadways, had the highest CO, whereas indoor environments, such as residences, offices, stores and restaurants, had the lowest levels of CO (Akland *et al.*, 1985).

1.3.3. Nitrogen Dioxide (NO_2)

Nitrogen dioxide is much more reactive than carbon monoxide. NO_2 can be both formed and removed chemically in the indoor environment and may therefore have greater special variability than CO, with a greater potential for discrepancies between personal and fixed monitoring stations concentration measurements (Harrison *et al.*, 2002). The major source of anthropogenic emissions of nitrogen oxides into the atmosphere is the combustion of

fossil fuels from stationary sources (e.g. power generation, indoor heating and cooking) and in motor vehicles. In ambient conditions nitric oxide (NO) is rapidly transformed into nitrogen dioxide by atmospheric oxidants, such as ozone (Brunekreef and Holgate, 2002). In their summary paper Ashmore and Dimitroulopoulou (2009) indicated that the most important indoor sources of NO_2 were gas appliances and kerosene heaters. The determinants of NO_2 concentrations in the UK homes included season, outdoor levels, cooking fuel, dwelling type, age of dwelling, presence of extractor fans, smoking and window opening. In the absence of indoor sources, NO_2 indoor concentrations in winter tend to be lower than in the summer, due to lower ventilation rate (Ashmore and Dimitroulopoulou, 2009).

The relatively low water solubility of NO_2 results in minimal mucous membrane irritation of the upper airway. The principal site of toxicity is the lower respiratory tract. Recent studies indicate that low-level NO_2 exposure may cause increased bronchial reactivity in some asthmatics, decreased lung function in patients with chronic obstructive pulmonary disease, and an increased risk of respiratory infections, especially in young children (U.S. EPA, 1994).

As a result of reviewing existing literature Weichenthal *et al.* concluded that evidence for a relationship between indoor NO_2 exposure and childhood asthma and/or increase in respiratory symptoms was inconsistent. The authors highlighted that exposures to NO_2 and volatile organic compounds (VOCs) were common in indoor environments and were suspected to trigger the same types of symptoms, therefore studies investigating indoor NO_2 effects should adjust for potential indoor VOCs exposures (Weichenthal *et al.*, 2007). Nevertheless, some of the reviewed studies found associations of elevated indoor concentrations of NO_2 with respiratory symptoms such as cough, breathlessness, wheezing and chest tightness, and asthma exacerbation (e.g. asthma attacks) (Franklin, 2007; Hansel *et al.*, 2008; Liu *et al.*, 2009).

1.3.4. Volatile organic compounds (VOCs)

Volatile organic compounds (VOCs) are organic compounds that have boiling point between 50 and 250°C (Godish, 2004). There are hundreds of VOCs in the air, which increases the complexity of indoor air pollution (Guo *et al.*, 2009). Some compounds such as benzene, dichloromethane and tetrachloromethane are known carcinogens (Franklin, 2007).

Major indoor and personal VOC exposure studies identified the role of indoor sources and traffic to personal exposure (Mendell, 2007; Ashmore and Dimitroulopoulou, 2009). VOCs are respiratory irritants that can be emitted into the indoor air of schools by building and interior finish materials, furnishings, office equipment such as some copiers and printers, as well as by cleaning and teaching products (e.g. paints and other art materials) (Adgate *et al.*, 2004; Rumchev *et al.*, 2004; Kim *et al.*, 2007; Weichenthal *et al.*, 2007; Guo *et al.*, 2009). There is a hypothesis that some adverse health effects of VOCs are due in part to reactions of the human organism to the total mixture of VOCs rather than to individual toxic chemicals (Wallace *et al.*, 1991). Because of use of wide range of synthetic materials in a day to day life, and due to the air tightness of buildings constructed since the mid-1970s, concentrations of many VOCs were found to be consistently higher indoors than outdoors in residences, schools and offices in developed countries (Wallace *et al.*, 1991; Franklin, 2007; Mitchell *et al.*, 2007). Researchers of an American study estimated that median lifetime cancer risks from VOC exposure based on modelled personal exposures were three times higher than those based on modelled outdoor concentrations, due to the importance of indoor emissions (Payne-Sturges *et al.*, 2004). Higher indoor concentrations of VOCs were found to be associated with allergy, breathlessness, asthma and respiratory symptoms in infants, preschool and school aged children (Daisey *et al.*, 2003; Franklin, 2007).

1.3.5. Formaldehyde (HCHO)

At room temperature, formaldehyde is a gas. It is also available in an aqueous solution as formalin. Formaldehyde has been classified as a probable human carcinogen by the Environmental Protection Agency (USA) (U.S. EPA, 1994). High occupational exposures to HCHO are considered a risk of nasopharyngeal cancer (Franklin, 2007).

Recent research has shown that HCHO indoor concentrations were several times higher that outdoors, suggesting important indoor sources (Franklin, 2007; Mendell, 2007). In indoor environments, formaldehyde can be produced by off-gassing from wood-based products assembled using urea-formaldehyde resins (plywood, particle board, medium density fibreboard) (Zhang *et al.*, 2006; Mendell, 2007; Guo *et al.*, 2009). Other sources include cigarette smoke, certain paints, varnishes and floor finishes (Mendell, 2007; Dales *et al.*, 2008).

Various acute symptoms from HCHO exposures indoors have been found including eye, nose and throat irritation as well as lower airway and pulmonary effects (Franklin, 2007). Because of its nature HCHO can be considered as both an acute toxicological agent and as

a potential human carcinogen, thus concentrations acceptably low for prevention of acute irritation symptoms may not protect against potential long-term cancer risk (Daisey *et al.*, 2003). In their review of existing scientific literature Weichenthal *et al.* (2007) indicated that formaldehyde was found to be associated with atopy, asthma, persistent wheezing, airway inflammation and other respiratory symptoms in children.

1.3.6. Carbon dioxide (CO_2)

An increase in the ambient level of carbon dioxide brings about a rise in the acidity of the blood and an increase in the rate and depth of breathing (Health Canada, 1987). Although carbon dioxide is not considered as a pollutant, many studies were conducted to investigate exposures to this gas. High concentration of carbon dioxide in school environments, usually dependent on indoor activity and occupancy levels, are thought to have negative effects on children's cognitive performance and general health (Coley *et al.*, 2007). CO_2 is also an indicator of ventilation rates, of the effectiveness of ventilation routines in the building and of excess of occupancy (Grimsrud *et al.*, 2006; Heudorf *et al.*, 2009; Almeida *et al.*, 2010). In their recent literature review Mejia *et al.* (2011) note that CO_2 concentrations vary depending on the length and level of occupancy in the classroom, type and quality of ventilation, room design (window area in particular), number of windows and window orientation. The authors also suggested that CO_2 concentrations can be considered as a measure of risk of transmission of airborne diseases throughout the classroom.

1.4. Variability of indoor and outdoor pollutant concentrations

In studies investigating health related effects of environmental factors exposure to harmful agents is often highly variable in time and space. As it is usually not possible to measure personal exposures on many individuals at once, exposure measurements can be performed at various fixed sites for a limited period of time (Brunekreef *et al.*, 1987).

Seasonal, weekly and daily variations in indoor pollutants concentrations are important to consider while assessing personal exposure (Fromme *et al.*, 2007; Sohn *et al.*, 2009). For example, several studies found that overall indoor air quality was poorer in winter rather than in other times of the year (Zhang *et al.*, 2006; Fromme *et al.*, 2007). This was attributed to lower ventilation in winter in comparison with other seasons, which led to the accumulation of pollutants generated by indoor sources. Activities taking place indoors and the number of people present in the room were proved to influence concentrations of PM, and CO_2 (Annesi-Maesano *et al.*, 2007).

Indoor levels of air pollutants may be influenced by infiltration of these pollutants from outdoors. For example, associations between the levels in the indoor and outdoor air were established for particulate matter (Riley *et al.*, 2002; Sarnat *et al.*, 2002). It was also found that for pollutants which are mostly generated outdoors, such as $PM_{2.5}$, elemental carbon and ozone, personal exposures of subjects increased with ventilation rates of indoor environments (Brown *et al.*, 2009).

Individuals' exposures can be modified by such factors as activity patterns, which determine encounters with various sources of exposure, and the rate at which exposure occurs (e.g. a relatively constant rate versus a variable rate) (Hatch and Thomas, 1993). Research have shown that correlations between readings from fixed area monitors and subjects' exposures measured with personal monitors, which are presumed to relate more closely to the true personal dose, are often weak (Wallace and Ziegenfus, 1985; Hatch and Thomas, 1993).

In view of the above, there is a need of further research into personal exposures of children in schools, which would take in account spatial, temporal and seasonal variations of pollutant concentrations. Since children move between various locations within the school, it is important to measure the concentrations of air pollutants at the locations where children spend most of their school hours, particularly at the times when most children are at these locations (Mejía *et al.*, 2011). To capture seasonal and inter-school variations in pollutant concentrations it is useful to measure the concentrations in several schools of different background pollution (e.g. schools situated in industrial areas vs. rural schools) throughout different times of the year.

1.5. Indoor air quality guidelines

There are established guidelines and regulations for ambient air pollution such as Directive 2008/50/EC on ambient air quality and cleaner air for Europe (The European Parliament and The Council Of The European Union, 2008) or National Ambient Air Quality Standards, USA (U.S. EPA, 2000), yet guidelines for indoor air pollution proved to be more difficult to established.

Current UK legislation sets standards for a variety of outdoor air pollutants (e.g. the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (DEFRA (UK), 2007), Air Quality Standards Regulations (2010), England/UK), however indoor air quality is less well legislated in the UK. Although there is no legislation specifically related to indoor air quality, some pieces of legislation cover such areas as smoking in public areas or

building regulations, which contribute to addressing to the quality of indoor air (O'Connell and Duarte-Davidson, 2007). UK regulations covering ventilation rates in schools include the Building Act (1984), the Building (Scotland) Act (2003) and the School Premises Regulation (1999), whereas Building Bulletin 101 Ventilation of School Buildings sets criteria for ventilation rates and CO_2 concentrations indoors (BB101, 2006).

In 2004 the UK Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP) published a document proposing guidelines for selected air pollutants in the indoor setting – Guidance on the Effects on Health of Indoor Air Pollutants, which among others included guidelines for a number of pollutants investigated under the SchoolAir pilot study, i.e. CO, NO_2 and HCHO (Department of Health, 2004).

In 2010 the World Health Organisation (WHO) published a set of updated indoor air quality guidelines. The primary aim of these guidelines is to provide a uniform basis for the protection of public health from adverse effects of indoor exposure to air pollution, and to eliminate or reduce to a minimum exposure to those pollutants that are known or are likely to be hazardous (WHO, 2010).

The table below presents some guidelines which were developed to control IAQ, including residential indoor air. Only the pollutants investigated under the SchoolAir pilot study were included in the table. All three of the reviewed sources provide guideline average concentrations for CO, NO_2 and HCHO, whereas only WHO and Health Canada contain guidelines for particulate matter exposures. In addition, Health Canada provides the guideline for acceptable CO_2 indoor concentrations. Comparing one hour average guidelines it is can be seen that all three sources are generally in agreement with each other, with the exception of Health Canada NO_2 guideline, which is 1.7-2.3 times higher than these in the other two sources. Besides Health Canada's $PM_{2.5}$ 24-hours mass concentration guidelines are 1.6 times higher than WHO guideline.

There are a number of occupational safety and industrial hygiene standards (most of them originating in the USA) which were not included into this table. Widely recognised National Ambient Air Quality Standards (USA) were not included into the table below either as they relate to ambient rather than indoor air. More detailed information can be found in an extensive report by the National Research Council Canada – Indoor Air Quality Guidelines and Standards, 2005, which covers some of the most well-established guidelines and standards relating to IAQ (including occupational safety and industrial hygiene standards, as well as guideline values used in Germany and Hong Kong) (Charles *et al.*, 2005).

Table 1 Indoor air quality guidelines

Pollutant	Guideline source		
	WHO (WHO, 2006; WHO, 2010)	**COMEAP, 2004** (Department of Health, 2004)	**Health Canada** (Health Canada, 1987; Health Canada)
CO	6 ppm (7 mg/m^3) [24h] 9 ppm (10 mg/m^3) [8h] 31 ppm (35 mg/m^3) [1h] **2010*	10 ppm (10 mg/m^3) [8h] 25 ppm (30 mg/m^3) [1h] 50 ppm (60 mg/m^3) [30min] 90 ppm (100 mg/m^3) [15min]	10 ppm (11.5 mg/m^3) [24h] 25 ppm (28.6 mg/m^3) [1h] **2010*
NO_2	20 ppb (40 µg/m^3) [year] 110 ppb (200 µg/m^3) [1h] **2010*	20 ppb (40 µg/m^3) [year] 150 ppb (300µg/m^3) [1h]	50 ppb (100 µg/m^3) [24h] 250 ppb (480 µg/m^3) [1h] **1987*
HCHO	0.1 ppm (0.1 mg/m^3) [30min] **2010*	0.1 ppm (0.1 mg/m^3) [30min]	0.04 ppm (50 µg/m^3) [8h] 0.1 ppm (123 µg/m^3) [1h] **2006*
$PM_{2.5}$	10 µg/m^3 [year] 25 µg/m^3 [24h] **2006*	–	40 µg/m^3 [24h] 100 µg/m^3 [1h] **1987*
PM_{10}	20 µg/m^3 [year] 50 µg/m^3 [24h] **2006*	–	–
CO_2	–	–	3,500 ppm (6,300 mg/m^3) [24h] **1987*

Notes: In square brackets are the times of exposure; h – hour(s), min – minutes; the year of guideline publications are indicated after asterisk (*).

Neither of the three sources summarised in the table above include guidelines on TVOC, however in their report Ajiboye *et al.* reviewed some other proposed guidelines (including documents produced by the Australian National Health and Medical Research Council, the Finnish Society of Indoor Air Quality and Climate and the Japanese Ministry of Health). In general, these sources advice that the concentration of TVOC in indoor air should not exceed 200-500 µg/m^3 (Ajiboye *et al.*, 2006).

Although carbon dioxide is not considered as a pollutant, its concentrations often serve as indicator of ventilation rates and can be used as a marker of changes in occupancy (Hui *et al.*, 2008). Inadequate ventilation and elevated CO_2 levels can lead to drowsiness, headaches, fatigue, and cause eye and throat irritation as well as impair learning ability. Additionally, high levels of CO_2 may indicate the presence and increased levels of other air pollutants that could affect occupants' health. According to the UK ventilation performance standards for school environment, the carbon dioxide levels in all teaching and learning spaces should not exceed 1,500 ppm average over the whole school day, i.e. 9:00 am to 3:30 pm (BB101, 2006). The same standards bulletin state that the maximum concentration of carbon dioxide should not exceed 5,000 ppm during the teaching day, and at any occupied time, including teaching, the occupants should be able to lower the concentration of carbon dioxide to 1,000 ppm.

The American Society of Heating and Air-Conditioning Engineers (ASHRAE) provides an indoor CO_2 value of 1,000 ppm as an indicator for where human bioeffluents (odours) may interfere with acceptable human comfort. However, this value serves only as a recommendation and is not a regulated standard.

Research in the area of IAQ is becoming of growing national and international importance, however the policy context in this area in not as well-developed compared to that for outdoor air pollutants (Charles *et al.*, 2005; WHO, 2006). Guidelines exist for ambient air pollutants, however, such guidelines cannot easily be used for indoor environments, due to differences in the patterns of pollutant types, size ranges and mixtures. At present there is a restricted amount of evidence on which guidelines and policy with regard to indoor air quality can be based on (Department of Health, 2004; Department of Health, 2006; Department of Health, 2009). Hence, research that contributes to the body of knowledge and reduces uncertainty in the area of indoor air quality is valuable.

Concluding, current evidence suggests that exposure to common indoor air pollutants has adverse health effects on children, and in particular on children with asthma and/or respiratory illnesses. High concentrations of air pollutants also increase the risk of developing adverse health among healthy children (Daisey *et al.*, 2003; Mendell and Heath, 2005).

SchoolAir is a pilot study aimed at assessing the hypothesis that poor air quality in schools is associated with increased prevalence of asthma, respiratory and allergic symptoms among primary school children. The study is unique in the way that it is looking simultaneously at several environmental parameters as well as at respiratory health effects in children. One of the aims of the overall SchoolAir pilot study, and the primary aim of this MPhil project, is to develop a methodology to model personal exposures of children to air pollutants by combining measurements in several indoors and outdoors locations within a school.

2. Materials and Methods

2.1. Study design

Four primary schools were selected for the pilot study conducted within the academic year 2009/2010. The four schools were of diverse size and environmental and socioeconomic backgrounds: one rural school from South–East England (referred to as R) and three suburban schools (referred to as S1, S2 and S3) from North–West of Greater London. School R was situated in a rural area, surrounded by cultivated fields, approximately 3 km from the nearest town and 1.5 km from a motorway. School S1 was 5 km from a motorway, 2.5 km from a Royal Air Force aerodrome, 2 km from a series of ponds surrounded by green recreational spaces, and 500 m from a railway. School S2 was within a close proximity of a major motorway (250 m away), in 600 m from a food production factory, 750 m from a railway and 3.5 km from a major airport. School S3 was situated within 600 m from a motorway, 1.5 km distance from a major airport, 2.5 km away from a large motorway junction and 6.2 km from a railway.

The study consisted of two major parts (see Table 3 for the schedule of measurements):

a) Exposure measurement in school environments (indoors and outdoors);
b) Health and background questionnaire survey of school children.

All children of school Year 3 in Schools S1 and S2 and children of composite Year 3 / Year 4 classes in School S3 (ages 7 to 9) were offered participation in the study, whereas participation was offered to all pupils in the rural school due to its small size (see Table 4 for study population details). Letters of permission were acquired from schools, and children were enrolled after signed informed consent was obtained from parents or guardians. The study has been ethically approved by the Research Ethics Committee at Brunel University.

2.2. Exposure measurement

2.2.1. Measurement rounds

Indoor and outdoor measurements in schools were carried out in representative locations of typical Year 3 children's exposure, during the length of an academic year 2009/2010. Three rounds of exposure measurements (in autumn, winter and summer) were performed to capture seasonal variability of indoor and outdoor levels of air pollutants in these schools. Each round involved a five day – Monday to Friday – monitoring in four locations: generally three indoors and one outdoor (see Table 3 and Table 5).

Three rounds of exposure measurements – in autumn, winter and summer – were performed in suburban schools (S1, S2 and S3) to capture seasonal variability of indoor and outdoor levels of air pollutants. Due to logistics reasons rural School R was included only into two rounds of measurements out of the three – in the autumn and summer rounds.

2.2.2. Measurement locations

As in daily life people (in this case children) move around and thus are exposed to various levels of pollutants (Monn, 2001), measurements were conducted in several school microenvironments. In schools S1, S2 and S3 the measurement locations were as follows: two "home" classrooms of primary Year 3 classes (where the children of relevant classes spent most part of the school day) – coded locations A and B; physical education / assembly hall – location C; and outdoors, in the schools' playgrounds – location D (see Table 5). These were chosen to cover the locations where the children of the investigated classes were more likely to spend the majority of their time during a school day. Two classrooms were selected to investigate whether the exposures measured in them (ME) would be different (within school classroom to classroom variation) and to be able to model and compare personal exposures (PE) of two different classes in each of the suburban schools.

In addition, in School S2 exposures were measured in a stand alone canteen building – location E – during lunchtime only (for approximately one and a half hours) on one day after the main measurements week in the winter round. Later these measurements were used in modelling of School S2 children's PE to represent their exposure to the measured pollutants during lunch times (in all three rounds of measurement: autumn, winter and summer).

In School R only one "home" classroom was monitored (location A), as due to the rural location and consequently the small size of the school there was only one composite class combining children of primary years 3 and 4. Monitoring station B was located in a corridor linking several classrooms with the physical education / assembly hall, whereas stations C and D were placed according to the same principle as in all other participating schools – in the physical education / assembly hall and in the outdoors playground respectively.

Equipment in the indoors locations were placed in children's usual breathing zone: at 55-90 cm from the floor level, depending on each particular room, to represent usual sitting and standing positions of children. The height of the outdoor monitoring station was 67 cm

from the ground level, and it was generally placed no more than one meter away from the school building, due to health and safety issues.

2.2.3. Monitoring instruments and parameters measured

The following air components concentrations and parameters were measured: five gaseous components – carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), total volatile organic compounds (TVOC) and formaldehyde (HCHO); airborne particulate matter (PM); temperature, and relative humidity of the air.

Particulate matter concentration levels were evaluated in two different ways for the length of a school day (7–8 hours). Particle counters (Aerocet 531; Met One Instruments, Inc., USA) were used for two particle size ranges: particles with aerodynamic diameter of greater or equal to 0.5 µm and greater or equal to 5.0 µm (usually up to 15.0 µm). Additionally, temperature and relative humidity were measured with this instrument. Measurements were continuous and expressed as minute averages over the time course. The difference for PM $\geq$ 0.5 µm and PM $\geq$ 5.0 µm counts was calculated to estimate particle count for PM size range 0.5 – 5.0 µm ($PM_{0.5\text{-}5.0}$, particles/L) and used in the analyses.

Following the results of the initial literature review and after conducting preliminary testing of the particle counters, it was decided to use number concentration mode of the particle counters rather than conventionally used mass concentration mode. The literature review revealed that there is some evidence that particle size, surface area and particle count combined might be more relevant exposure indices for health than particle mass concentration especially in case of fine and ultrafine particles (Levy *et al.*, 2000; Morawska, 2010). Moreover, trial runs of the equipment indicated that instruments had poor mass sensitivity and low resolution. However, the limitation of the counter mode of the equipment used in this study is the wide range of particles sizes counted together (0.5-5.0 µm).

The other method used to assess concentration levels of particulate matter was by filtering air through 0.8µm polycarbonate filter membrane (Nuclepore, PC MB 25 mm 0.8µm) using air filter pumps (AFC 123 Personal Air Sampler – Casella Limited, UK) with following investigation of particle composition, size differentiation and count using scanning electron microscope (SEM). The results of SEM analysis of the filters collected during the study is not presented in this research paper, but are planned to be presented separately elsewhere.

Continuous measurements (minute averages) of **gaseous pollutants** including carbon dioxide (CO_2 (ppm)), nitrogen dioxide (NO_2 (ppb)), carbon monoxide (CO (ppm)), formaldehyde (HCHO (ppb)), total volatile organic compounds (TVOCs (ppm)); and temperature (ºC) and relative humidity (%) of the air were monitored with wireless automatic concentration monitor (IAQ Profile Monitor, PPMonitor Wireless unit; PPM Technology, UK). These measurements were transferred wirelessly into a computer. Due to problems with calibration of the formaldehyde and TVOC sensors in the gas monitoring units, measurements of these two pollutants were omitted for the autumn and winter rounds of measurements, but were included into the analysis for the summer round, after the sensors were properly re-calibrated.

Below are specifications of the sensors included into the PPMonitor Wireless unit (PPM Technology, 2010):

An electrochemical NO_2 sensor had a measuring range of 0-5 ppm. It had cross sensitivity with chlorine (Cl_2) and hydrogen sulphide (H_2S), which the author did not consider to be important, as there were no suspected significant sources of either Cl_2 or H_2S in schools.

An electrochemical CO sensor had a measuring range of 0-100 ppm and cross sensitivity with hydrogen (H_2) and ethylene (C_2H_4), and with nitric oxide (NO) to a lesser extent. The only chemical that might be important to be taken in account for the purposes of the SchoolAir study is NO.

A photo ionisation detector TVOC sensor had a measuring range of 0-20 ppm with minimum detectable quantity of 0.01 ppm. It targeted VOCs and other gases with ionization potentials <10.6 eV. The TVOC sensor did not measure HCHO – it was measured with a separate sensor.

An electrochemical HCHO sensor had a measuring range of 0-10 ppm with the resolution of 0.01 ppm and precision of 2%. 94% of all instrument readings met NIOSH (National Institute for Occupational Safety and Health, USA) criteria for an acceptable method when measuring 0.3 ppm of formaldehyde over a relative humidity range of 25-70%. The NIOSH criterion for acceptability is that all results fall within ± 25% of the true value at the 95% confidence level.

A non-dispersive infrared sensor for CO_2 had a measuring range of 0-5,000 ppm (with guaranteed accuracy up to 1,000 ppm). Accuracy: at 22°C when compared against a certified factory reference ± 40 ppm + 3% of reading.

2.3. Development of methodology for personal exposure estimation

The following steps were undertaken in order to estimate personal exposure of children (by school class):

1. Time-activity patterns of children, as a class, were monitored by a researcher during each school day of the exposure measurements rounds;
2. An exposure-activity matrix was developed for each class;
3. Personal exposure estimation was carried out for two classes in suburban schools and one class in the rural school based on the activity matrices and actual measurements of pollutants' concentrations in the relevant school microenvironments during particular time periods. This was done separately for each round of measurements (three rounds in Schools S1-S3 and two rounds in School R) and for each pollutant.
4. Detailed investigation, statistical analysis and comparisons with exposures measured with a static equipment unit in a relevant "home" classroom were performed for one class per school – Class A.

The above steps were necessary to estimate personal exposure of children to air pollutants during a school day without the need to place a personal exposure monitor on each child. Below the steps are described in details.

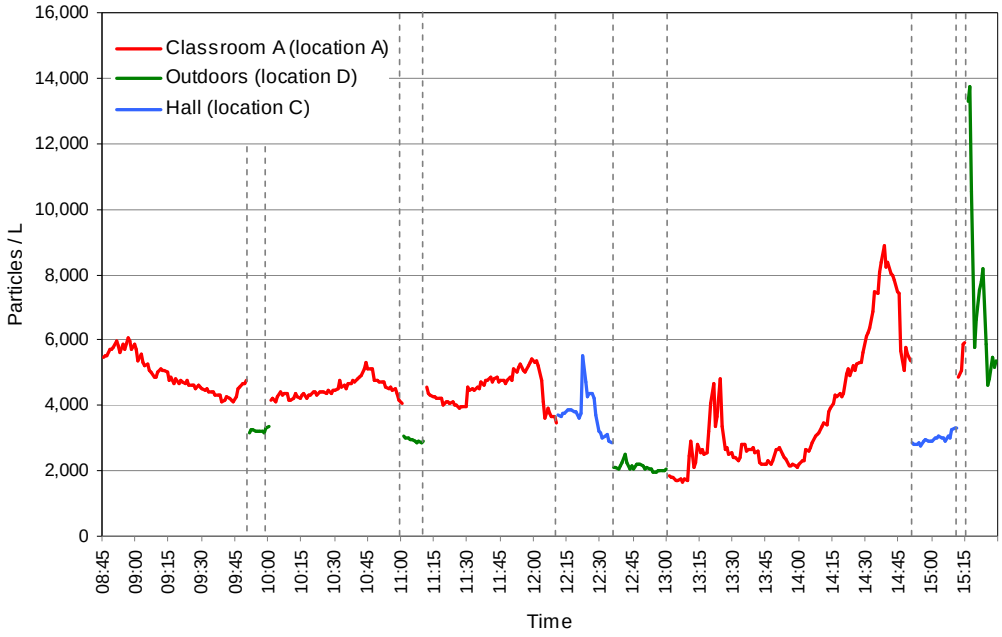
2.3.1. Monitoring of children's activities

Monitoring and recording of children's activities during each day of the measurement rounds were performed in order to create a representative exposure pattern for each class according to the time the children spent in different locations. Also these allowed to assess how occupancy and activity in a particular room affected measured air quality parameters, such as concentration of PM and various gases.

In order to establish how long children were spending in different locations within their schools, children's movements between the locations and their activities were recorded in a diary by a researcher every day of the measurement rounds (Monday to Friday within each round). Locations, such as classroom A, classroom B, hall or outdoor playground, were recorded together with timings of when children stayed there, what activities they were undertaking, and the times when they changed their locations (see Figure 1 and Table 2 for illustration). In suburban schools this was done simultaneously for three primary Year 3 (or

composite Year 3/4) classes. Usually the three "home" classrooms were located next to each other, so it was possible to monitor all three classes at the same time. In the rural school activity matrices were created for one class only – a composite class of primary years 3 and 4.

Figure 1 Illustration of personal exposure estimation principle.



Notes: Figure 1 graphically represents personal exposure to concentrations of $PM_{0.5\text{-}5.0}$ of one class during one school day. Personal exposure is based on air quality measurements conducted in four locations and timings of children's daily activities in these locations.

2.3.2. Matrix development

The next step was to model personal exposure of children of each class using the combination of actual measurements in the four locations. Since one of the aims of the study was to investigate the influence of IAQ on children's health during usual school days, only the measurements for the occupied part of the day were taken into account. Measurements for air pollutants were taken between 8:45 and 15:30, from five days (Monday to Friday) within each of the three rounds of measurements.

The occupied part of every day was broken into 406 one-minute intervals, where minute 1 was 8:45 and minute 406 was 15:30, by which time the school day was over in all four of the participating schools and children were supposed to go home or to join some after school activities. A matrix of time by location – "personal exposure matrix" – was created for each class for each day within the three rounds of measurements, based on the records of children's activities and movements. For instance, from minute 1 to minute 15 class X were playing in the outdoor playground, minutes 16-91 – having a lesson in classroom A,

minutes 92-136 – having an assembly in the hall, and so on until minute 406. A detailed example of such PE matrix for one class and one day of measurements is shown in Table 2 and the relevant graphical representation with real time concentrations of $PM_{0.5-5.0}$ is shown in Figure 1. Personal exposure matrices were created for each monitored class (i.e. it was done for groups of children rather than for individuals), for each day of measurements in all three seasons of measurements.

Table 2 Illustration of personal exposure estimation principle – Personal Exposure Matrix for Class A (one day of measurements).

Time	Minute number	Location Description	Location code	Activity
8:45-9:50	1-66	Classroom A	A	Lesson
9:51-10:00	67-76	Outdoors	D	Break
10:01-11:00	77-136	Classroom A	A	Lesson
11:01-11:10	137-146	Outdoors	D	Break
11:11-12:10	147-206	Classroom A	A	Lesson
12:11-12:35	207-231	Hall	C	Lunch
12:36-13:00	232-256	Outdoors	D	Break
13:01-14:50	257-366	Classroom A	A	Lesson
14:51-15:10	367-386	Hall	C	Assembly
15:11-15:15	387-392	Classroom A	A	Packing bags
15:16-15:30	393-406	Outdoors	D	Going home

2.3.3. Personal exposure estimation

On the basis of the pupil activity matrices personal exposure of children of two primary classes per each suburban school and of one class in School R was modelled using SAS 9.1 statistical software. Data for the appropriate times were transferred from the dataset with the actual measurements of pollutants' concentrations to the personal exposure estimation data file using the occupancy information in the PE matrix. This was done for every day of all three rounds of measurements and for each of the measured pollutants.

2.3.4. Solving gaps in measurements

If there were short gaps in measurements in some particular locations (up to 20 min) and there was an obvious trend in the direction of the concentrations measured from the point when the measurements stopped to the point they resumed (upward, downward or flat), the missing values were predicted in Excel 2007 using linear interpolation. Such short gaps usually happened due to equipment malfunction (usually connectivity issues with the wireless gas monitors due to school structure).

If the measurements in a particular location were not available for a longer period of time, which could happen due to major equipment malfunction or where measurements were not conducted at all, these locations were assigned with available measurements which would closely reflect the type of this environment without measurements. For example, if due to equipment failure there were no measurements available for an outdoors location on a particular day the outdoors measurements from a previous or following day were taken and used for extrapolation.

In case when the unmeasured environments were completely different form the measured locations, e.g. if a class was attending a swimming pool, these periods of time were omitted from the calculations of daily and weekly personal exposures.

2.4. Statistical analysis

In order to visualise daily and weekly variability within each school and variations between schools descriptive graphical analysis of measured pollutants was carried out in Excel 2007. Further statistical analysis was performed using SAS version 9.1 statistical software (SAS, Cary, NC). Firstly, box plots representing concentration distributions of measured pollutants over each week of measurements were created for all locations in each school in each round of measurements.

Secondly, descriptive statistical analysis of concentrations measured with fixed monitors in various locations within each school was carried out. Summary statistics tables of weekly exposures for all locations and schools in each of the measurement rounds were created. The tables included such fields as number of observations, mean, standard deviation, median, 25^{th} and 75^{th} percentile.

Similarly, box plots and descriptive statistics tables were created for modelled personal exposures, in order to visualise the differences in measured and personal exposures in different schools, locations within the schools and in various times of the year.

Notwithstanding the fact that $PM_{0.5-5.0}$ distribution was found to be right skewed and log-normally distributed, in which case geometric mean (GM) and geometric standard deviation (GSD) are often used (Brauer *et al.*, 1999; Levy *et al.*, 2000; Lai *et al.*, 2004; Zhang *et al.*, 2006), it has been decided against the use of GM and GSD, following the advice from the article by Parkhurst. The author argues that the GM is always smaller than the arithmetic mean and is biased, as it downplays larger values relative to smaller ones. Parkhurst also advices that *"it is undesirable to use estimators that are biased low when seeking to protect public health from dangerous organisms or chemicals"* (Parkhurst, 1998). GMs and GSDs were included in descriptive statistics tables for measured $PM_{0.5-5.0}$ for comparison, but were not calculated for any other measured pollutants.

Comparisons of personal and measured exposures (by school, by season) were performed using independent group t-test, Satterthwaite method, with two-tailed tests and level of significance of 5%. The results of t-tests allowed for quantitative comparison of ME and modelled PE.

Linear regression resulting in coefficients of determinations (R^2) was performed to model relationships between measured and personal exposures. The coefficient of determination gives the proportion of the variance the dependant variable (in this case personal exposure) which can be "predicted" or "explained" by the independent variable (measured exposure). The coefficient of determination is the ratio of the explained variation to the total variation (Altman, 1991). R^2 takes on values between 0 and 1, and the closer R^2 is to unity, the better the independent variable (e.g. measured exposure) can explain the variation in the dependant variable (e.g. personal exposure) (Carriquiry, 2004). Thus R^2 greater than 0.5 means that over 50% of the variance in modelled PE can be explained by ME, whereas R^2 under 0.5 means that only under a half of variance in PE can be explained by ME.

Coefficients of variation (CV) were calculated for the weekly means of measured exposures and for weekly means of the modelled personal exposures (for each pollutant, by school, by season).

$$CV = SD / Mean,$$

where SD is the standard deviation of the relevant mean (Petrie and Sabin, 2005). CV can also be shown as percentage. The advantage of the CV is that it is unitless, which allows CVs to be compared to each other in ways that other measures, such as standard deviations, cannot be. The standard deviations of two variables cannot be compared to each other in a meaningful way to determine which variable has greater dispersion because they may vary greatly in their units and the means about which they occur. On the contrary, CVs can be compared in a meaningful way: the variable with the smaller CV is less dispersed than the variable with the larger CV, provided that both variables contain only positive values (UCLA: Academic Technology Services). Percentages of change in CVs between exposures measured in Classroom A and relevant modelled personal exposures of Class A were calculated for each pollutant, school and season to measure the change in variability between ME and PE. Then these CV changes were tabulated and graphed to allow comparisons.

2.5. Health and background questionnaire survey

The child's health and home environments were assessed with the use of a questionnaire. The questionnaire was administered once in the course of the school year (in the autumn round of measurements) to children's parents/guardians via the schools. Parents/guardians were asked to return the completed questionnaires to their child's class teacher to be later collected by the researchers.

The questionnaire used for this pilot study was based on the questionnaire designed by the International Study of Asthma and Allergies in Childhood (ISAAC) (Pearce *et al.*, 1993; ISAAC Steering Committee, 1998; Austin *et al.*, 1999; Pearce *et al.*, 2007), which was shortened and slightly modified to our needs. This study's questionnaire consisted of four sections. The first part included personal information such as name, home postcode, gender and ethnicity of the child. The second section consisted of questions on respiratory symptoms, such as wheezing, cough and asthma ever and in the last 12 months. The third section of the questionnaire was dedicated to rhinitis and irritation, including hayfever and problems with sneezing or a runny or a blocked nose – ever and in the last 12 months. And finally, there was a general questionnaire part, which included questions on other illnesses of the child, medication taken, on history of asthma and allergies in the immediate family,

allergens at home, cooking and heating sources at home, and questions on socio-economic status of the family, including questions on parental education and occupation (See Appendix 1).

All personal identifiable information was removed from the database prior to analyses and each child was assigned with a unique identification number.

In order to link the results of the health survey to modelled personal exposures, proportions of children with and without symptoms in each school were assessed in conjunction with the overall means of modelled PEs. Overall PE means were calculated for each pollutant combining measurements for the occupied part of the day from all three measurement rounds.

Firstly, the proportions of children with no symptoms reported, as well as those with one, two, or three or more symptoms, were calculated for each school. This was done for two groups of symptoms separately: symptoms ever and symptoms in the last 12 months (according to the responses in the relevant sections of the health questionnaire). Secondly, overall means and standard deviations of modelled PEs were calculated for each pollutant. And, finally, the results of the health survey were graphed and assessed together with the mean PEs.

3. Results

3.1 Measured exposure

3.1.1 Measured exposure – extent of data

Numbers of missing observations of exposures measured *in classrooms* were in general low and ranged from 0.1% to 4.4% of total number of observations (Table 6). The only exceptions were the gaseous air components' measurements. Due to connectivity issues with wireless gas monitors in Schools S1 and S3 during the autumn and winter rounds of measurements (because of the size of the schools and positions of the monitoring stations), for some locations gas concentrations were not recorded by the computer every minute, as it should, but were recorded more irregularly – with occasional gaps of 2 to 10 minutes. This still can be considered as continuous measurement. The maximum proportion of missing observations in gas measurements in a classroom was in School S3 in the winter round – 22.2%. The problem was resolved in the summer round of measurements with inclusion of two additional wireless routers into the wireless system, which strengthened the network. For more details on ME missing observations numbers and other monitoring issues in *all locations* see Table 6.

3.1.2. Measured exposure – descriptive statistics

3.1.2.1. Particulate matter ($PM_{0.5-5.0}$)

Table 9 and Figure 2–Figure 5 presents descriptive statistics for measured particulate matter (in all locations, schools and seasons). The figures and the table show that in most occasions mean concentrations and variability of $PM_{0.5-5.0}$ measurements in schools' physical education and assembly halls were higher than those measured in classrooms, except for school S1 in the summer round of measurements. Weekly mean (standard deviation, SD) range for exposures measured in halls across the schools and seasons was 4,583(1,859) - 19,759(12,808) particles/L whereas in classrooms the range was 3,936(1,486) - 17,598(11,473) particles/L. This could be explained by more pronounced human activities in halls (e.g. during physical education lessons, or school assemblies), which cause re-suspension of particles into the air, in comparison with classrooms (where children usually sit at their desks for the majority of time).

Concentrations of $PM_{0.5-5.0}$ measured in various *indoor* locations were in most cases higher in the winter round of measurements compared with the autumn and summer rounds. The winter weekly mean (SD) range was 3,936(1,486) - 19,759(12,808) particles/L, whereas the autumn was 4,796(2,134) - 8,373(3,229) particles/L and the summer range was

4,010(1,259) - 8,422(5,424) particles/L. This may be explained by lower ventilation rates and the fact that children spend more time indoors as well as wear more clothes during the winter period, causing re-suspension of particles. Comparing the autumn and summer indoor particle concentrations only, in schools R and S3 concentrations of $PM_{0.5-5.0}$ were slightly higher in the autumn, whereas in schools S1 and S2 – in the summer.

Overall, across all seasons, the highest particle concentrations *indoors* were recorded in School S2 in the winter round: 15,867(9,642) - 19,759(12,808) particles/L; and the lowest – in School R in the summer round of measurements: 4,010(1,259) - 5,111(1,627) particles/L.

Outdoor particle concentrations in suburban schools (S1, S2 and S3) were higher than concentrations measured indoors in all three rounds of measurements. In School R, on the contrary, outdoor concentrations of $PM_{0.5-5.0}$ were lower than indoors, which might be a sign that in rural environments particles are mostly generated and/or re-suspended by indoor activities, whereas in suburban environments outdoor sources of particles prevail.

Outdoor $PM_{0.5-5.0}$ daily means in School S3 in the winter round of measurements revealed extreme values. The daily means for the four days of the week (Monday to Thursday) exceeded the mean of particle concentrations measured in all schools and all seasons by 9 to 18 times; and if compared with the mean of all schools and rounds *excluding* the winter measurements in School S3 – by 85 to 166 times depending on the day (see Table 8 for details). Friday measurements did not exceed the overall outdoor mean of $PM_{0.5-5.0}$ concentrations.

One of the explanations of these extreme particle concentrations measurements may include thick long lasting fog, which might have caused water droplets to be included into particle counts. An investigation of fog droplet size distributions of natural fogs showed that the radius of measured water particles lied in the range of 0.3 μm to 70 μm, whereas droplet concentrations ranged from 24 droplets/cm^3 to 4,400 droplets/cm^3 (Garland, 1971). It must be noted that a large proportion of the samples examined (nine out of the twenty five samples) in that fog study was found to show droplets of less than 1 μm in diameter. A study conducted by Sanders and Selby revealed that there were very few droplets with diameter exceeding 10 μm in the sampled fogs (Sanders and Selby, 1968), whereas Pruppacher and Klett stated that fogs are usually characterised by small drops with diameter from 2.5 μm to few tens of micrometers (Pruppacher and Klett, 1997). These sources indicate that a large proportion of water particles in natural fogs lie within the size range investigated in the SchoolAir pilot study (0.5-5.0 μm) and thus these water droplets

might have been counted together with particles of other origins. Another possible explanation of such extreme particle counts in the SchoolAir study could be malfunction of the instrument. Extreme concentrations recorded outdoors in School S3 in the winter round of measurements were discarded from further analysis and from personal exposure modelling.

After exclusion of outdoor measurements recorded in School S3 in the winter, the highest *outdoor* weekly means were those in School S2 in the winter: 41,584(30,030) particles/L and the lowest – in School R in the summer: 3,943(2,629) particles/L.

3.1.2.2. Carbon monoxide (CO)

Both indoor and outdoor weekly mean concentrations of carbon monoxide did not vary considerably across the seasons, schools and locations (Table 11 and Figure 6–Figure 8). The highest weekly mean values recorded were in Classroom A in School R in the summer round (mean (SD): 1.03(1.10) ppm) and in Classroom B in School S3 in the winter round of measurements (1.03(0.3) ppm). The lowest weekly mean CO concentrations were recorded in the corridor of School R in the summer (0.22(0.22) ppm), although the corridor measurements can not be directly matched with measurements in any other school, as this was a unique monitoring station location in one school only.

It can be noted that the highest CO variability within a week of measurements was in the classroom in School R during the autumn round (1.03(1.10) ppm) and that in each of the measurement seasons average CO concentrations in classrooms were higher in schools R and S1 than in classrooms of the other two schools – S2 and S3. This can indicate that there were more indoor sources of CO in the classrooms of schools R and S1. For example, it was observed that levels of CO increased when teachers and pupils were using white board markers and pens during a lesson, however, no detailed investigation of this was conducted.

Outdoor weekly means (SD) ranged from 0.28(0.08) ppm to 0.50(0.17) ppm across all schools and seasons.

3.1.2.3. Nitrogen dioxide (NO_2)

Limited variability was recorded for nitrogen dioxide across the seasons, schools and locations (see Table 12 and Figure 9–Figure 11). Interestingly, both the lowest and highest weekly means were calculated for School S3 in the winter round of measurements: the lowest mean (SD) was 39.5 (6.4) ppb in Classroom B and the highest was 71.8 (5.2) ppb

for the outdoors location. It can be noted that in all schools and all seasons outdoor NO_2 concentrations were higher than concentrations in any of the indoor locations. The range of *indoor* weekly means (SD) across all schools and seasons was 39.5(6.4)-56.1(5.9) ppb, whereas *outdoor* range was 56.9(4.6) - 71.8(5.2) ppb. No season or school specific patterns in the weekly mean concentrations of NO_2 were found.

3.1.2.4. Total volatile organic compounds (TVOC)

Total volatile organic compounds concentrations measured in the autumn and winter rounds of measurements were discarded due to calibration issues with the TVOC sensors in the gas monitors. The sensors were re-calibrated in the spring 2010 and the summer TVOC measurements were included into this report.

No particular patterns were observed in the TVOC weekly means across schools and locations in the summer round of measurements (see Table 13 and Figure 12). For example, in some schools outdoor weekly means were higher that those measured indoors, but in the others the indoor values were higher. Overall the smallest weekly mean (SD) was calculated for Classroom A in School S1 – 0.11(0.13) ppm, and the highest weekly mean (SD) was for the Hall of School R – 0.72(0.32) ppm.

3.1.2.5. Formaldehyde (HCHO)

Formaldehyde concentrations measured in the autumn and winter rounds of measurements were discarded due to calibration issues with the formaldehyde sensors in the gas monitors. The sensors were re-calibrated in the spring 2010 and the summer formaldehyde measurements were used in this report.

Indoor weekly mean concentrations of HCHO lied in the range of 14.2-36.5 ppb. Variability of indoor concentrations of formaldehyde was higher in the schools R and S1 in comparison with the schools S2 and S3 (see Table 14 and Figure 13). For example, weekly mean (SD) in Classroom A in School S1 was 36.5 (72.1) ppb, whereas in Classroom A in School S2 it was 17.6 (13.5) ppb. Also Figure 13 shows that there were more outliers outside 1.5 interquartile range in indoors locations in schools R and S1, rather than in schools S2 and S3.

Variations in mean *outdoor* HCHO levels were moderate in comparison with indoor means. Weekly means (SD) of the outdoors concentrations ranged from 2.8(3) ppb to 7.3(4.9) ppb. Outdoor means were 2.4 to 12 times lower than the concentrations measured

indoors in all schools, which suggest that there were indoor sources of HCHO present in every investigated school.

3.1.2.6. Carbon dioxide (CO_2)

Weekly mean *indoor* concentrations of carbon dioxide varied considerably across seasons, schools and locations, mostly depending on ventilation routines and the rate of natural outdoor-indoor air exchange through splits and gaps in windows and walls (see Table 15 and Figure 14–Figure 16).

The highest indoor CO_2 concentrations were recorded in the winter rounds of measurements (weekly mean (SD) range: 897(498) – 3,754(1,181) ppm) and the lowest – in the summer round (633(165) – 1,852(1,175) ppm). This held true for all three suburban schools (there was no winter measurements in School R). Overall, School S3 had the highest weekly mean CO_2 concentrations recorded in each of the measurement seasons.

In all schools and all seasons the level of CO_2 in physical education / assembly halls was lover that that measured in classrooms. This might be explained by the fact that children spent longer time during a school day in their home classrooms, whereas occupation of halls varied with time and on many occasions halls were unoccupied for most part of the day. Also, as classrooms were much smaller in room volume than halls, the population density (number of people per m^3 of air) during the periods of occupancy was usually higher in classrooms rather than in halls. Across the seasons weekly mean (SD) range of CO_2 measured in halls was 671(243) - 1,267(54) ppm and in classrooms – 767(357) - 3,754(1,181) ppm.

There was very little variation across the schools and seasons in the CO_2 concentrations measured *outdoors*. The range was from 395(17) ppm (School R in the summer) to 450(41) ppm (School S3 in the autumn round).

3.2. Personal exposure

3.2.1. Personal exposure – extent of data

The percentages of missing values in modelled PE datasets were overall higher in comparison with the percentages of missing values in MEs, and ranged between 0.2% and 15.1% (see Table 7), with the exception of one class in School S3 in the winter round, where percentages of missing values in PE to gaseous air components were higher (up to 32.7%) due to the wireless gas monitors connectivity problems, and the issues with the

outdoor $PM_{0.5-5.0}$ concentrations discussed in Section 3.1.2.1. Outdoor $PM_{0.5-5.0}$ daily means for the four days of the week (Monday to Thursday) in School S3 in the winter round of measurements revealed extreme values and were excluded from the children's personal exposure estimations. The measurements from the last day of the week (Friday) did not exceed the overall outdoor mean of $PM_{0.5-5.0}$ concentrations (across schools and seasons) and were included into personal exposure estimations.

3.2.2. Personal exposure – descriptive statistics

3.2.2.1. Particulate matter ($PM_{0.5-5.0}$)

In majority of cases modelled personal exposures to particulate matter were higher than exposures measured in relevant classrooms (see Table 16 and Figure 2 –Figure 4). The highest weekly mean PEs were during the winter round of measurements, range: 5,549(3,989) - 19,981(17,496) particles/L. The lowest weekly mean PE across the schools and seasons was for Class A in School R in the summer period: 4,858(1,700) particles/L, and the highest – in Class A in School S2 in the winter: 19,981(17,496) particles/L.

3.2.2.2. Carbon monoxide (CO)

The weekly means of modelled PEs to carbon monoxide were generally slightly lower than the mean MEs in the relevant classrooms (see Table 17 and Figure 6–Figure 8). Overall, there was limited variation in PEs to CO across the schools and seasons – the weekly mean (SD) range was 0.35(0.15) - 0.85(0.59) ppm. It can be noted that the highest CO variability of modelled PE within a week of measurements was in the autumn round in School R (0.82(0.88) ppm).

3.2.2.3. Nitrogen dioxide (NO_2)

Overall, modelled PEs to NO_2 were slightly higher than ME measured in relevant classrooms. There was little variation of modelled PE to nitrogen dioxide across the schools and seasons (see Table 18 and Figure 9–Figure 11). The lowest weekly mean (SD) PE was 47.6(9.0) ppb – for Class B in School S1 in the winter, and the highest was 57.9(7.0) ppb – for Class A in school S2 in the autumn round.

3.2.2.4. Total volatile organic compounds (TVOC)

Weekly means of modelled PEs to TVOC in all schools were slightly higher than MEs measured in classrooms (see Table 19 and Figure 12). There was limited variability across the schools. The lowest weekly mean (SD) of modelled PE was 0.20(0.21) ppm for Class B in School S1 and the highest was 0.36(0.23) ppm for Class B in School S2.

3.2.2.5. Formaldehyde (HCHO)

In the summer round of measurements (the only round available) modelled weekly mean PEs were either lower then formaldehyde exposures measured in classrooms or were approximately at the same level with them (see Table 20 and Figure 13). The lowest PEs were for both of the classes of School S2: 15.9(13.7) ppb and 16.5(12.4) ppb, and the highest – for classes of School S1: 40.7(74.9) ppb and 40.7(63.9) ppb, which are over twice as high as the means in School S2.

3.2.2.6. Carbon dioxide (CO_2)

Weekly means of the modelled PE to CO_2 were in the majority of cases lower than the weekly means of CO_2 concentrations measured in relevant classrooms (see Table 21 and Figure 14–Figure 16). The highest weekly mean CO_2 PEs were in the winter round of measurements (range: 1,261(504) - 2,834(1,792) ppm) and the lowest – in the summer (809(419) - 1,525(1,159) ppm). In each of the seasons modelled PEs were higher in School S3 in comparison with other schools (from 23% to 260% higher, depending on a season).

3.3. Comparison of measured exposure and modelled personal exposure

In order to compare exposures measured in classrooms, which sometimes can be used as a proxy for personal exposures of children in schools (Smedje *et al.*, 1997; Smedje and Norback, 2001; Mi *et al.*, 2006; Zhao *et al.*, 2008), with the modelled PEs an independent group t-test was used. T-tests were performed only for comparisons of exposures measured in Classroom A with the modelled exposures of Class A – for each of the schools. Classroom A (and consequently Class A) was chosen, as in the overall duration of the measurements there were more equipment failures and malfunctions in classrooms B rather than in classrooms A.

As the variances of the two compared groups (measured and personal exposures) were found to be unequal, two-tailed p-values were calculated using Satterthwaite's method. Figure 18–Figure 23 and Table 22 show differences between the means of PE and ME. Namely, the figures and the table show results of the following deduction: weekly mean PE minus weekly mean ME – by school, by season, and the confidence intervals associated with them. Conventional level of significance of 5% was used (α=0.05).

3.3.1. Results of t-test

Particulate matter ($PM_{0.5-5.0}$)

Figure 18 and Table 22 show that in the majority of cases PEs of Class A to particulate matter were higher that exposures measured in Classroom A. The only exception was School R in both the autumn and the summer rounds of measurements, for which PE was either almost equal to or slightly lower than ME. The results of the t-test were statistically significant, except for one occasion (School R in the autumn round).

Thus, in the majority of cases, if fixed monitor PM measurements were used to represent children's PE, it would have been an underestimation of the real personal exposure, as higher exposures in other locations during the school day would not have been considered at all.

Carbon monoxide (CO)

The t-tests performed showed that in most cases the modelled PEs to carbon monoxide were lower than measured exposures (Figure 19 and Table 22), with the exception of the schools S1 and S2 in the summer round (where PEs were slightly higher than MEs) and School S2 in the autumn (where ME and PE were almost equal). The results of the t-test were statistically significant, except one – for School S2 in the autumn round ($p = 0.268$).

Nitrogen dioxide (NO_2)

Figure 20 and Table 22 represent the results of t-test for nitrogen dioxide. In all cases PEs were slightly higher than MEs – the mean differences were under 6 ppb. All t-test results were of high statistical significance ($p < 0.001$).

Total volatile organic compounds (TVOC)

For the schools R, S1 and S2 in the summer round of measurements modelled PEs to TVOC were higher than exposures measured in classrooms and the results of t-tests were highly statistically significant ($p < 0.001$) (see Figure 21 and Table 22). For School S3 the mean PE and ME were almost equal and in this case the result of the t-test was not statistically significant ($p = 0.768$).

Formaldehyde (HCHO)

In case of formaldehyde modelled PEs were slightly lower that MEs on three occasions – in the schools R, S2 and S3 (all the three results were highly significant with $p < 0.001$), whereas in School S1 personal exposure was slightly higher than ME with the p-value of 0.077 (see Figure 22 and Table 22).

Carbon dioxide (CO2)

For carbon dioxide modelled personal exposures were in most cases lower than measured exposures, with the exception of the schools S1 and S2 in the summer round of measurements (where PEs slightly exceeded relevant MEs) and School S2 in the autumn round (where mean weekly PE and ME were almost equal) (Figure 23 and Table 22). All results of the t-test were statistically significant, except for School S2 in the autumn round ($p = 0.429$).

3.3.2. Results of linear regression

Linear regression models correlating estimated personal exposures (Class A) to measured concentrations (in Classroom A) were run by school, by season to estimate what proportion of modelled PE could be explained by the relevant ME. Table 23 shows the results of the linear regression modelling, namely the coefficients of determination (R^2). Most of the R^2 coefficients in the table were less then 0.5, which meant that only 50% or less of the personal exposures could be explained by the measured exposures.

All coefficients for **NO_2** were less than 0.4. Only two coefficients of determination calculated for **CO_2** exceeded 0.5, and five out of eleven lied in the range from 0.4 to 0.5. Four out of the eleven calculated R^2 coefficients for **$PM_{0.5\text{-}5.0}$** were greater than 0.5 and two coefficients were in the range 0.4 to 0.5. Results for **CO** seem to be inconclusive: one coefficient was less than 0.4, whereas six were greater than 0.5 and the remainder four falling in between 0.4 and 0.5. All four calculated R^2 for **formaldehyde** were over 0.44, with two of them exceeding 0.7 suggesting that either most part or at least around half of the variation in PE in the summer season could be explained by the variation in ME. Results for **TVOC** show that only one of the four coefficients calculated exceeded 0.5, whereas the other three were below 0.2.

3.3.3. Comparison of coefficients of variation of measured and personal exposures

Coefficients of variation (CV) were calculated for weekly mean MEs (measured in Classroom A in each school) and weekly mean modelled PEs for Class A, then the percentage of CV change between ME and PE were calculated. Table 24 and Figure 24 show that in the vast majority of cases there was a 10% or greater increase in variability, when CVs of PEs were compared to CVs of relevant MEs.

For $PM_{0.5\text{-}5.0}$, NO_2 and CO_2 the increase in CV was equal or greater than 20% in more than half of the cases, in particular in autumn and winter rounds of measurements. For CO in

three of the eleven cases CV change was over 20%, in two cases it was equal 20% and in the rest of the cases it was below 20%.

There were five cases when CV change exceeded 100%: three cases in the autumn round ($PM_{0.5-5.0}$ in School S1 and NO_2 and CO_2 in School S3) and two – in the summer, both for TVOC. In one of the latter cases the change was 253% (TVOC in School R). In two of these extreme cases the number of PE observations were slightly lower than the numbers of ME observations, which might have inflated the percentage of CV change.

There were three exceptions, when a slight negative change in CV was revealed, i.e. CO in School S2 and NO_2 in School R in the autumn round of measurements, and HCHO in School S1 in the summer. These changes were in the range from -3% to -7%.

The results of CV comparison indicate that in general modelled personal exposures were more variable than relevant measured exposures. Thus using modelled PEs for assessment of health effects in populations can provide better estimation of exposure-response association, rather than using stationary monitors (e.g. in one classroom).

3.4. Health survey

3.4.1. Health survey – extent of responses

There were no compulsory questions in the questionnaire. As it was distributed in paper form, the researchers had no control over completion rates. Although in the explanation letter accompanying the questionnaire the importance of the information provided for each question was highlighted, whether or not to answer a question was left to the discretion of the respondent.

Table 25 shows the number and percentage of questions that were not answered by the respondents, where an answer was not provided at all, or where only part of the question was answered. The table shows missing answers by part of the questionnaire where these unanswered questions belong to (i.e. health, home environment and socioeconomic status parts) and whether there was one, two or three or more missing answers in the returned questionnaire. In the health part of the questionnaire the percentage of returned questionnaires with one unanswered question ranged between 0% and 8.6% of the total number of questionnaires returned (across all schools); 0% to 2.3% were missing two answers, and 1.7% to 11.4% had three or more missing answers. In the home environment part of the questionnaire the proportion of returned questionnaires with one missing answer ranged from 5.6% to 31.8%; with two missing answers – from 0% to 13.3%, and with there

or more missing answers – from 0% to 11.4%. In the socioeconomic status part there were 5.2%-27.3% of questionnaires with one missing answer, 0%-13.8% with two missing answers and 3.4%-40.9% with three or more answers missing. Overall, the two schools with the highest proportion of questions that were left unanswered were School S2 and School S3 (the latter had a very low response rate altogether – only 12.4% of its targeted population).

It also may be noted that in School S2 there were several questionnaires where the respondents skipped whole pages of the questionnaire without providing any answers. This might be partially explained by the multi-nationalism of the children attending this particular school and their families, with a possibility that the level of the English language competency of some of the parents / guardians was not high enough to understand the questions in full. This issue was also bought to the attention of the researchers at the initial meeting with the school's headmaster.

3.4.2. Results of health survey

There was a very low questionnaire response rate in Schools S3 and although this school is included in Figure 25 and Figure 26, it is excluded from further discussion in this section of the report. Thus the results of the health survey for the schools R, S1 and S2 only will be compared.

Out of the three schools the lowest proportion of children without any respiratory or allergic symptoms reported was observed in School S1 (both for "ever" symptoms – 48.2%, and for symptoms "in the last 12 months"- 50.0%). School S1 had the highest proportion of children whose parents / guardians reported that they had one respiratory or allergic symptom. Again, it held true for both "ever" symptoms (20.4%) and for symptoms "in the last 12 months" (18.5%). Also School S1 had the highest proportion of children with three or more respiratory and/or allergic symptoms – 14.8% for "ever" symptoms and 18.5% for symptoms "in the last 12 months".

School S2 revealed the highest proportion of children with two respiratory and/or allergic symptoms (18.2% for symptoms "ever" and 15.9% for symptoms "in the last 12 months").

The rural school (R) had overall more children without any symptoms reported and the least proportions of children with any number of symptoms.

3.4.3. Comparison of health survey results with outcomes of personal exposure modelling

Figure 27 and Table 26 present mean modelled personal exposures of Class A children (means across all seasons of measurement) and relevant standard deviations. The figure shows that Class A children in School S1 had the highest mean modelled personal exposures to CO – mean(SD): 0.71(0.47) ppm and HCHO – 41(75) ppb. For this school HCHO personal exposure was 156% higher than for the children in School S2, 71% higher than in School S3 and 8% higher than in School R. CO exposures were 38% higher than in School S2, 12% higher then in School R and 9% higher than in School S3.

Class A in School S2 had the highest mean PE to particles (10,634(12,781) particles/L), TVOC (0.27(0.26) ppm) and marginally higher to NO_2 – 56(8) ppb. $PM_{0.5-5.0}$ exposure in this school was twice as high as PE of School R children, 46% higher than PE in School S3 and 32% higher than in School S1. Exposure to TVOC was 28% higher than in School S2, 12% and 8% higher than schools S3 and R. NO_2 personal exposure was 4% to 8% higher than in the other schools.

Children in School S3 had highest PE to CO_2 (2,213(1,462) ppm). It was 117% higher than in School S2, 73% than in School R and 35% higher in comparison with School S1.

Children of the rural school (R) had lowest PEs to $PM_{0.5-5.0}$ (5,173(2,301) particles/L), and NO_2 (52(7) ppb), whereas personal exposures to CO, TVOC, HCHO and CO_2 were somewhere in the middle of the inter-school range.

The modelling exercise showed that PEs of Class A children in School S1 were the highest of the three schools in regard to CO and formaldehyde, whereas PEs to PM, and CO_2 were second highest (after schools S2 and S3 respectively). The results of the health survey revealed that children in school S1 had overall the highest prevalence of respiratory and/or allergic symptoms. On the contrary, in School R the modelled yearly mean PEs were overall in the lower end of the inter-school yearly means range, and the health survey results indicated that the children of the rural school had the lowest prevalence of symptoms. Thus the preliminary findings may support the theory that higher personal exposures to air pollutants in school environments may associate with poorer respiratory health. However, this health to PE comparison is only a rough estimation and no significance inferences can be drawn at this stage.

4. Discussion

The SchoolAir study examined air quality in four primary schools across three distinctive seasons. Moreover, a methodology for children's personal exposure assessment using air quality measurements in several microenvironments around the school in combination with children's time-location-activity records was developed and tested. The advantage of the developed approach is that it allows for assessment of personal exposure of groups of children (e.g. classes in a school) without the need to place a personal monitor on each individual. This is particularly important in case of younger children as personal monitors can be heavy to carry around, cumbersome or have fragile parts that can be damaged in the process of personal exposure monitoring. This approach also can provide a cheaper alternative to personal monitors.

The study is unique in the way that many factors were considered simultaneously including air components and parameters (five gaseous components: carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), total volatile organic compounds (TVOC) and formaldehyde (HCHO); airborne particulate matter (PM), temperature, and humidity), as well as personal exposure and respiratory health effects in children were assessed. In addition, information on several other groups of factors was collected using the questionnaire – such as socio-economic status of children's families, their environmental exposures at home or in a local neighbourhood.

The results of this MPhil study showed that modelled personal exposures were in the majority of cases significantly different from the exposures measured with fixed monitors in a classroom, and that variability of pollutants' concentrations was generally much higher for PEs rather than for MEs. Both of the factors – the correctly estimated mean personal exposure and its variability – are very important in the investigations of dose-response relationships when assessing health outcomes.

Below the main results of the SchoolAir pilot study are discussed and compared with previously conducted studies.

4.1. Measured exposure

4.1.1. Particulate matter ($PM_{0.5-5.0}$)

The results of particle number concentration measurements showed high variability. Variability was observed at different levels: during each school day at one location, between locations in the same school, across seasons in each school, as well as across the

schools. High daily variability of PM concentration can be explained by the presence/absence of pupils and the intensity of their activities in various indoor locations within the school. Similar conclusions were made by the authors of previous studies (Annesi-Maesano *et al.*, 2007; Guo *et al.*, 2010).

Higher indoor weekly means were calculated for the winter round of measurements compared with other seasons. This was observed for all three schools where measurements took place in the winter season. The findings are consistent with a recent study of indoor air in primary schools conducted in Germany, which showed that levels of particle mass concentrations in classrooms (collected using filters with pore size of 0.4 μm) were higher in winter then in summer (Oeder *et al.*, 2011). A study conducted in Korea (Sohn *et al.*, 2009), reported that for computer rooms and laboratories in the investigated schools the mass concentration of PM_{10} was higher in the winter than in the autumn or summer. However, their results showed that for classrooms the seasonal differences were not very prominent, but the inter-school means were somewhat higher in the autumn round. Higher particle number concentrations in winter might be explained by lower ventilation and the fact that children spent more time indoors in winter than in autumn or summer. Consequently, more particles are generated and re-suspended by children indoors.

The results for outdoor particle mass concentrations of a study conducted by Oeder *et al.* (2011) showed that summer outdoor concentrations were somewhat higher than those in winter. The three schools measured within the SchoolAir project in both summer and winter seasons revealed varying results. In School S1 weekly mean outdoor $PM_{0.5\text{-}5.0}$ levels in the winter and in the summer were at approximately the same level, whereas in School S2 winter weekly mean was more than four times higher than the summer mean. Winter measurements results for School S3 were discarded, as they revealed erroneously high values, thus no winter to summer comparison can be made for this school.

Outdoor particle concentrations were higher than indoors in the case of the suburban schools in all seasons, but not in the rural school, where, on the contrary, outdoor concentrations were lower than indoors. These results suggest that indoor particle concentrations in suburban environments are affected by outdoors, where the concentration of PM is higher due to the influence of traffic exhausts and other outdoor particle sources, whereas in the rural settings indoor sources of particles prevail.

Although there are many studies of indoor air reporting on mass concentrations of various size ranges of particulate matter as well as particle number concentrations of ultrafine particles (those under 0.1 μm in aerodynamic diameter), the number of previously

published studies that report number concentrations within the size range measured in the SchoolAir project, namely 0.5-5.0 µm, is very limited. The numbers of ultrafine particles or even combined ranges of ultrafine and fine particles (those under 2.5 µm) published in relevant scientific literature can not be compared to the numbers of $PM_{0.5-5.0}$. Particle number size distribution studies have shown that the majority of particles in the air are smaller than 0.1 µm in diameter (Wu *et al.*, 2008). Whereas the number concentrations in studies investigating ultrafine or combined ultrafine and fine particle ranges are of the order from N x 10^3 to N x 10^5 particles/cm^3 (Morawska *et al.*, 2003; Guo *et al.*, 2008; Hoek *et al.*, 2008; Guo *et al.*, 2010), the results of the current study are of the order from N to N x 10 particles/cm^3 (or in the units used throughout this thesis: N x 10^3 to N x 10^4 particles/L).

The results of several previous studies that reported number concentrations of particles in size ranges similar to the range investigated in the SchoolAir project are described below.

The authors of a small research project conducted in 2009, which aimed at assessing particle emissions at stone quarries, and in rural and urban areas in Palestine were using the same equipment as in the SchoolAir pilot study – Aerocet 531 (Met One Instruments, Inc., USA) (Vieli, 2009). The author measured particle number and mass concentrations in various outdoor locations at and around stone quarries, in busy urban streets and in rural areas. Their 15 minute averages of the number concentrations of particles in 0.5-5.0 µm range was 1,180 to 22,521 particles/L in rural and urban locations, and from 2,486 to 22,573 particles/L at/around stone quarries. $PM_{0.5.-5.0}$ number concentrations were derived from the mean concentrations of particles over 0.5 µm in diameter and those over 5.0 µm that were reported. These particle concentration ranges are comparable to the outdoor weekly means of concentrations measured in the SchoolAir study.

A study conducted in Switzerland measured indoor particle number concentrations in three different recreational halls during various public events: three concerts and one ice hockey game (Junker *et al.*, 2000). The ranges of means of PM number concentrations measured during each event were from 14,100 to 112,000 particles/L for particles of 0.75-1.0 µm in diameter, and 2,640-56,400 particles/L for 1.0-2.0 µm particles. In order to approximate the reported size ranges to the range measured in the SchoolAir study, the reported mean concentrations were summed up to get the counts of 0.75-2.0 µm particles. The lower range of the mean number concentrations for $PM_{0.75-2.0}$ is comparable with the SchoolAir results, however their upper end of the range are four times as high as the highest outdoor weekly mean in the SchoolAir project. This may be explained by the fact that concert and

hockey halls accommodate much more people at once than usual school indoor environments, thus there might be much more sources of generation and re-suspension of particles in big public halls.

The authors of another Swiss study of indoor air investigated bioaerosols and particle number concentrations in a mailing room (Brandl *et al.*, 2005). Means of 4 hours of continuous measurements of background levels of particles inside the mailing room, i.e. when no mail handling was taking place, were 14,688 particles/L for particle size 0.5-1.0 μm, and 1,613 particles/L for 1.0-5.0 μm range. The sum of the two size ranges' means is 16,301 particles/L, which is comparable to the highest weekly means of indoor PM measurements in classrooms (in School S2 in winter) and to some of the outdoor levels measured in the SchoolAir study: i.e. all seasons' outdoor levels in School S1, summer outdoor levels in School S2 and autumn levels in School S3. Particle number concentrations in the study by Brandl *et al.* were much higher when unloading of mail bags was taking place: 1-hour means were 27,849 particles/L for 0.5-1.0 μm, and 13,284 particles/L for 1.0-5.0 μm. These values are also comparable with the SchoolAir measurements.

Two North American studies were conducted with the aim of measuring number concentrations of particles of different size ranges in various indoor and outdoor microenvironments (Brauer *et al.*, 1999; Levy *et al.*, 2000). Both studies reported their results as geometric means (GM) and geometric standard deviations (GSD) of particle counts expressed in particles/cm^3, hence the SchoolAir measurements were converted from particles/L into particles/cm^3, and the relevant weekly GMs and GSDs were calculated. The results of these transformations are shown in Table 10. The SchoolAir GMs are comparable with the results of the Brauer's study: their GMs for 0.5-1.0 μm particles were in the range of 3.1 to 12.2 particles/cm^3, and for 1.0-5.0 μm particles – 0.5 to 1.3 particles/cm^3, whereas SchoolAir GMs for $PM_{0.5\text{-}5.0}$ were in the range of 1.3 to 14.2 particles/cm^3 with one outdoor GM of 25.0 particles/cm^3 – in School S2 in winter. However, the results of Levy *et al.* are two times to an order of magnitude lower than the SchoolAir results, even though both studies, Brauer *et al.* and Levy *et al.*, used the same make of particle counters. Levy *et al.* referenced the previously published study of Brauer *et al.* (1999) and attributed the disparity to either geographic differences or an instrumentation issue.

Although it was not possible to directly compare the SchoolAir particle number concentrations with the results of previous studies investigating relationships between

airborne particles and health, there are some generalised findings that fine particles in school environments affect the health of pupils and school personnel. A Swedish school based study demonstrated that respirable dust was related to impaired mental performance of pupils and airway infections in adult school staff (Norback and Smedje, 1997). A significant relationship between the concentration of airborne respirable particles and new self-reported pet-allergy in schoolchildren was revealed in a later study by the same authors: odds ratio, OR = 1.8, per 10 $\mu g/m^3$, $p<0.05$ (Smedje and Norback, 2001). Moreover, a study conducted in the USA showed that fine particles were much more strongly associated with asthma-related responses in school children, namely increased lower respiratory symptoms and decreased peak expiratory flow rate, than coarse particles (Schwartz and Neas, 2000).

The above examples indicate that further investigation of the possible relationship between number concentrations of fine particles in school environments and children's health would be beneficial, and thus can be recommended for any follow up research project that might result from the pilot SchoolAir study.

4.1.2. Carbon monoxide (CO)

Carbon monoxide measurements showed limited variability. Higher concentrations were observed during particular activities taking place in classrooms, e.g. use of white board markers and art lessons in schools R and S1. The results of this study's indoor CO concentration measurements are comparable to the levels advised by the Environmental Protection Agency, USA. EPA state that average levels in homes without gas stoves vary from 0.5 to 5 ppm (U.S. EPA, 2011), whereas the SchoolAir results showed weekly mean indoor CO concentrations ranging from 0.22 to 1.03 ppm. The SchoolAir results are also comparable to the measurements from the school indoor air study of Sohn *et al.* (2009) conducted in Korea, although their mean CO concentrations measured in classrooms in summer were 4 to 8 times higher than those measured in this study (the across the schools summer mean of 2.64 ppm compared to the range 0.31-0.67 ppm measured in the summer in classrooms in this study).

The SchoolAir weekly mean concentrations were lower then the overall mean of CO concentrations measured in living rooms of 270 homes in the UK – 1.7 ppm (Croxford *et al.*, 2006). This can be explained by the fact that in the UK homes study 5% of measurements were from homes with malfunctioning / "problem" gas appliances, thus producing a higher overall mean.

In schools R and S1 weekly means of CO concentrations measured in classrooms and their variability were higher than in the other two schools, except for the winter round when the highest weekly mean was calculated for School S3.

In the majority of cases weekly means of outdoor CO concentrations were lower and with smaller variability than those measured indoors. In other cases weekly mean indoor and outdoor concentrations were almost equal. This can indicate that there were minor indoor sources of CO in the schools investigated. These findings contradict the results of Sohn *et al.* (2009), which showed that the indoor CO concentrations measured in schools were lower than those outdoors, suggesting that the main source of CO was outside. This discrepancy might be due to the differences in the outdoor environments of the schools investigated in this study and in the study by Sohn *et al.*, for example, whether the schools were located in urban, suburban or rural settings, whether they were situated close to major roads, or had industrial sources nearby.

The author did not find any previously published studies that would evaluate the effect of exposure to low levels of CO on the respiratory health of children. The only study that might be considered as marginally relevant is the study conducted in Mongolia, which compared rural and urban cohorts of children aged 5-15 years (Dashdendev *et al.*, 2001). The authors measured ambient and exhaled CO levels, conducted lung function spirometric tests and anthropometric measurements. Mean ambient levels were 0.63 ppm for urban environments and 0.21 ppm for rural environments, which is comparable with the SchoolAir outdoor weekly means, whereas exhaled CO levels were twice as high in urban children as in rural children (0.94 ppm *vs.* 0.47 ppm). The results of the study showed that normal FEV_1 (forced expiratory volume in 1 second) was 40% higher in rural children than in urban children, which might reflect the adverse effect of air pollution in the cities, as indicated by increased levels of both ambient and exhaled CO. However, these results have to be interpreted with caution as no direct causality between ambient CO levels and changes in lung function in children can be established. Rather a complex of various air pollutants and other environmental factors present in urban environment can cause deleterious respiratory health effects.

4.1.3. Nitrogen dioxide (NO_2)

The SchoolAir indoor weekly means (SD) ranged from 39.5(6.4) ppb to 54.1(5.1) ppb (across schools and seasons), whereas the outdoor means range was 56.9(4.6) ppb to 71.8(5.2) ppb. The indoor levels in the SchoolAir study were higher than those observed in previously conducted studies. For example, results of a school based study showed that

mean (SD) concentrations of NO_2 indoors in classrooms heated with either electric or flued gas heater was 15.5(6.6) ppb, which is 2.5 to 3.5 times lower than the SchoolAir results, whereas in rooms heated by unflued gas heaters it was 47.0(26.8) ppb, which is comparable with the results of this study (Pilotto *et al.*, 2004). Two home based studies showed similar results: one study found that mean indoor NO_2 concentrations at homes were 30.0(33.7) ppb (Hansel *et al.*, 2008), and the result of the second study was 31.6(40.2) ppb (Breysse *et al.*, 2005). The results of both studies are comparable with the lower end of the SchoolAir indoor weekly means.

The SchoolAir outdoor weekly means were higher than indoors in all seasons, indicating that major sources of NO_2 were outdoors, likely traffic. This agrees with the results of a school based study conduced by Mi *et al.* (2006), which showed that mean indoor concentrations of NO_2 across several schools were lower than the mean outdoor concentrations. Compared with the results of outdoor measurements of Liu *et al.* (2009) with a mean of 18.3 ppb and 5^{th}-95^{th} percentile 12.3-27.0 ppb, the SchoolAir outdoor concentrations were up to four times greater. The differences between the results of the current study and previously conducted studies may be explained by utilisation of different methods. The mentioned studies used passive NO_2 diffusion samplers (Palmes tubes), whereas in the SchoolAir study an electrochemical sensor was used and minute average concentrations were logged in real time.

The review of previous studies aimed at investigating health effects in relation to indoor air quality revealed that even at levels of NO_2 lower that the ones observed in the SchoolAir study some deteriorating health effects were found. For example, a Chinese study of air quality in schools and asthma and respiratory symptoms in pupils showed that indoor NO_2 was associated with current asthma (OR = 1.51 per 10 $\mu g/m^3$, $p<0.05$), and current asthma medication (OR = 1.45, per 10 $\mu g/m^3$, $p<0.01$), even though their mean results were slightly lower than the SchoolAir weekly means. The mean NO_2 concentration of 30 classrooms was 55 $\mu g/m^3$ (29.2 ppb) (Mi *et al.*, 2006). The results of conventional multiple logistic regression from another study conducted in Chinese schools showed that indoor NO_2 was associated with nocturnal attacks of breathlessness (OR = 1.45, per 10 $\mu g/m^3$, $p<0.05$) (Zhao *et al.*, 2008). In this case the mean of NO_2 measured in 31 classrooms in different schools was 39.4 $\mu g/m^3$ (20.9 ppm), which is again lower than the SchoolAir weekly means.

4.1.4. Total volatile organic compounds (TVOC)

Measured TVOC concentrations did not reveal any particular pattern in the summer round of measurements that would be similar for all schools. Weekly means varied across locations within each school differently. The range of indoor weekly means (SD) was 0.11(0.13)-0.72(0.32) ppm, and of outdoor means (SD) – 0.13(0.19)-0.60(0.47) ppm. We suspect that outdoor concentrations, such as those in schools S1 and S2, might have been influenced by emissions from plastic cover of the weather enclosure, where the equipment was placed. It can be recommended that in any future studies a proper made for purpose weather enclosure constructed with inert materials should be used to avoid VOC off-gassing.

The authors of an American study investigating air quality in elementary and middle schools found that the levels of TVOC appeared to be higher in portable classrooms (Godwin and Batterman, 2007). In the SchoolAir study slightly higher levels of TVOC, in comparison with weekly means in other classrooms, were found in both of the portable classrooms in School S3. In those two classrooms weekly interquartile ranges were wider than in classrooms in other schools. Higher TVOC levels might have been caused by emissions of chemicals from the newer building materials used in construction of these mobile classrooms, as well as by chemicals from cleaning products that were regularly used in those classrooms at the end of a school day. However no direct conclusions can be made due to the low number of investigated classrooms.

Although there has been a number of scientific papers published on concentrations of VOCs in homes (Rumchev *et al.*, 2004; Khalequzzaman *et al.*, 2007) and school indoor environments (Mi *et al.*, 2006; Zhang *et al.*, 2006; Godwin and Batterman, 2007; Sohn *et al.*, 2009), the results of these studies were presented in $\mu g/m^3$ rather than in parts per million. Thus a direct comparison of their results with the SchoolAir study results is not possible, as TVOC is a group of chemical compounds and $\mu g/m^3$ values can not be easily converted to ppm.

The results of the previous studies were converted into ppm using the following formula (CCOHS, 2000):

$$Concentration\ (ppm) = 24.45 * concentration\ (mg/m3) \div gram\ molecular\ weight$$

An average molecular weight of VOCs of 75 gram/mole was taken to convert previously published data in mg/m3 into ppm, following the worksheet by Perry, Pyron & McCown Consultants / Innovating Manufacturing Technology (IMT).

The results of the following comparisons, however, have to be interpreted with caution, for two reasons. Firstly, as VOCs are a group of various chemicals, each of the study might have targeted some of them, but not the others, thus the arbitrary chosen average TVOC's molecular weight of 75 gram/mole may not reflect the actual average weight of the VOCs investigated in each study. Secondly, the reviewed studies used different methods of VOC detection and measurement, and thus only cautious comparison of the results obtained with these varying measurement methods is possible (Wallace *et al.*, 1991; European Commission, 1997).

The results of a school air quality study by Godwin and Batterman (2007) were one to two orders of magnitude greater than the SchoolAir results. Their mean concentrations of TVOC of measurements conducted in 64 rooms in four elementary and five middle schools was 58.0 $\mu g/m^3$. Following the suggested conversion method it equals 0.019 ppm, which is at least an order of magnitude smaller that the SchoolAir indoor weekly means. Their outdoor means were 10.44 $\mu g/m^3$ (0.003 ppm), which is at least two orders of magnitude smaller than the SchoolAir outdoor means (Godwin and Batterman, 2007). A study of home indoor quality in Hong Kong resulted in a mean TVOC concentration of 46.1 $\mu g/m^3$ (0.015 ppm), which is again an order of magnitude smaller that the SchoolAir results. These big differences in results are possibly explained by the difference in methods used to quantify TVOC concentrations. Both of the previously conducted studies used passive samplers to collect the chemicals from the air and then analysed the contents of samples in a laboratory, whereas in the SchoolAir project a real time photo ionisation detector was used (PPMonotor Wireless, PPM Technology, UK). A Japanese study that utilised two different methods simultaneously – an active and a passive sampler – to measure certain VOCs showed that the two methods produced different results. Sometimes means derived from a passive sampler's measurements were higher than means from an active sampler and sometimes *vice versa* (Shinohara *et al.*, 2004).

The results of the SchoolAir study are comparable with the results of the US Environmental Protection Agency's TEAM study (Total Exposure Assessment Methodology), where indoor means of TVOC were in the range of 1.0-3.0 mg/m^3 (0.33-0.98 ppm) and outdoor means of 0.5-0.7 mg/m^3 (0.16-0.23 ppm) (Wallace *et al.*, 1991).

TVOC were found to have adverse health effects. For example, a study in Swedish schools showed that TVOC were related to chronic airway symptoms (nasal catarrh, blocked up nose, dry or sore throat and irrigative cough), chronic general symptoms (headache, abnormal tiredness, sensation on getting a cold, nausea) and chronic eye symptoms (eye

irritation, swollen eyelids) (Norback *et al.*, 1990). The mean TVOC concentration in that study was 130 μg/m^3 (0.042 ppm). Another study found that current asthma was more frequent among pupils exposed to higher levels of TVOC in school (Smedje *et al.*, 1997). While the mean level of TVOC concentration was 26 μg/m^3 (0.0085 ppm), the odds ratio was 1.3 per 10 μg/m^3, $p<0.001$.

4.1.5. Formaldehyde (HCHO)

Outdoors weekly means for formaldehyde were consistently lower than those indoors for all schools suggesting that indoor sources of HCHO prevailed over outdoor sources. The range of weekly means (SD) for indoor locations was 14.2(22.4) - 41.9(62.8) ppb, and for outdoors – 2.8(3.0) - 7.3(4.9) ppb. In comparison, Sohn *et al*. (2009) reported the following range of HCHO concentration for indoor locations in schools – mean (SD): 0.09(0.11)-0.22(0.28) ppm, which is at least a factor of six higher than the results of the SchoolAir study. Interestingly, Zhao *et al.* (2008) reported that mean outdoor concentrations in Chinese schools were higher than those measured indoors: means (SD) were 5.8(0.6) and 2.3(1.1) μg/m^3 respectively (which is 4.7(0.5) and 1.8(0.9) ppb). Whereas outdoor mean results of Zhao *et al.* are comparable with the SchoolAir outdoor means, their indoor results are 8 to 23 times lower than the SchoolAir indoor weekly means. The authors also found associations between indoor HCHO and wheeze (OR = 1.38, per 1 μg/m^3, $p<0.05$) and nocturnal attacks of breathlessness (OR = 1.42, per 1 μg/m^3, $p<0.001$).

Mi *et al.* (2006) reported mean concentration of formaldehyde inside schools of 9.4(6.9) μg/m^3 (or 7.7(5.6) ppb), which is closer to the SchoolAir results for outdoor locations, rather than to indoors means. However, their indoor levels of HCHO were not significantly associated with respiratory symptoms.

A study in Swedish schools showed that increase in incidence of asthma diagnosis was found in relation to higher HCHO concentrations in a classroom (OR = 1.2, per 10 μg/m^3) (Smedje and Norback, 2001). The authors emphasise that these pollutant-health relationships were found despite low concentrations: the mean of all classroom HCHO concentrations was 8 μg/m^3 (6.5 ppb) with a maximum average concentration in a classroom of 72 μg/m^3 (58.6 ppb). Similar odds ratio for relations between HCHO in indoor air in schools and current asthma were calculated at even lower mean concentrations of formaldehyde. An earlier study in Sweden resulted in OR = 1.1, per 10 μg/m^3, $p<0.05$, with mean level of HCHO being under 5 μg/m^3 (4.1 ppb) (Smedje *et al.*, 1997).

4.1.6. Carbon dioxide (CO_2)

Considerable variations were revealed for measured carbon dioxide concentrations – daily, across different location within the same school and across schools and seasons. Weekly mean concentrations depended on ventilation routines, such as frequency of opening windows to air the room, and air tightness of each room. On many occasions daily mean concentrations of CO_2 exceeded recommended guideline values – both the American guideline of 1,000 ppm (ASHRAE, 2007) and the British one of 1,500 ppm (BB101, 2006). These results are a matter of concern as previous studies have shown that high levels of CO_2 in classrooms influence children's cognitive functions. A study conducted in a primary school in England demonstrated that attention processes of pupils were significantly lower when the concentrations of CO_2 in classrooms were high (Coley *et al.*, 2007). A Norwegian study, which included CO_2 measurements in 22 classrooms and performance tests of 550 pupils from 5 schools, also showed that children performed poorer in environments with high CO_2 levels (Myhrvold *et al.*, 1996). High concentrations of CO_2 were shown to be associated with pupils' absenteeism. A study conducted in the USA reported that 1,000 ppm increases in the difference between indoor and outdoor CO_2 concentrations were associated with 10-20% relative increases in pupils' absence, and the associations were statistically significant (Shendell *et al.*, 2004).

School S3 revealed the highest weekly mean concentrations of CO_2 measured in classrooms, which can be explained by the air tightness of classrooms and lack of ventilation routines. The classrooms investigated in School S3 were located in "mobile" stand-alone buildings constructed within the last 10 years and it was noticed that on several occasions throughout each of the round of measurements the windows were not opened at all throughout the whole school day. Across the seasons the range for weekly mean concentrations measured in classrooms of School S3 was 1,830(1,227) - 3,754(1,181) ppm.

School S2, on the contrary, showed the lowest classroom weekly means in all the three rounds of measurements with the range of 767(357) - 1,488(600) ppm across seasons. In the duration of the autumn and winter measurements round there were old single glazed windows in both classrooms investigated in School S2, which were replaced with new double glazed ones in April 2010 during the school break, before the summer round of measurements. Thus before the installation of new windows the natural air exchange rate between the classrooms and the outdoor environment through construction gaps in windows and walls was high (it is expected that it was higher than in the other three schools investigated), whereas after the installation of the new double glazed windows the

teachers of School S2 practiced a robust airing routine when all or majority of classroom windows were open during breaks between lessons.

Weekly mean concentrations of CO_2 were generally lower in physical education and assembly halls in comparison with classrooms. This might be explained by the fact that children spent longer time during a school day in their home classrooms, whereas occupation of halls varied with time and on many occasions halls were unoccupied for the most part of the day. Also as classrooms were much smaller in room volume than halls, the population density (number of people per m^3 of air) during the periods of occupancy was usually higher in classrooms rather than in halls.

4.2. Personal exposure

Due to a limited amount of previously published research results which would contain data on both personal exposure and exposure measured with fixed monitors in indoor environments, in some cases it was not possible to compare the results of the SchoolAir study with any relevant results of previous studies. There are even fewer personal exposure studies conducted in schools.

4.2.1. Particulate matter ($PM_{0.5-5.0}$)

In all three rounds of measurements modelled personal exposures to particulate matter were higher than those measured in relevant classrooms in suburban schools, and the highest PE was in the winter. However, in School R modelled PEs were slightly lower than classroom MEs, as in both rounds of measurements conducted in the rural school weekly means of $PM_{0.5-5.0}$ number concentrations were higher in the classroom rather than in other indoor locations or outdoors.

For the suburban schools weekly mean outdoor concentrations were higher that modelled PEs, whereas for the rural school PEs were higher than outdoor particle number concentrations and, in turn, concentrations measured in the classroom were higher than modelled PEs. These results suggest that whereas in suburban environments outdoor sources of particles prevail, in rural settings indoor concentrations or PM are higher due to human activities.

The results of PE modelling in this study are not in agreement with some previous studies. For example, in their review paper Ashmore and Dimitroulopoulou (2009) refer to the U.S. Environmental Protection Agency's Particle Total Exposure Assessment Methodology (PTEAM) study which showed that personal exposures to PM_{10} were higher than both

indoor and outdoor particle concentrations. However, the results of PTEAM and the current study can not be compared directly, as PTEAM study used different methods of PE assessment (personal exposure monitor – a pump with a filter – was used to collect particles), different range of particles were investigated (with aerodynamic diameter less than 10 µm) and the study was conducted at homes, where exposures to particles emitted by such sources as cooking and tobacco smoke may be considerably higher than in schools (Özkaynak *et al.*, 1997).

It was not possible to find any previously published studies that would report personal exposures to particles of the same or close size range that was investigated in the SchoolAir study, as well as express results using number rather than mass concentrations. Therefore no direct comparisons of modelled personal PM exposures with previous studies are presented.

4.2.2. Carbon monoxide (CO)

In most cases modelled weekly mean PEs to carbon monoxide were lower than MEs in relevant classrooms (except for schools S1 and S2 in the summer). The range of modelled weekly mean PEs was 0.35-0.85 ppm. The SchoolAir results were lower than the results of two studies in Finland. The results of the study of preschool children's personal exposure to CO published in 2001 showed that the daily average personal exposure of 302 preschool children was 2.1 mg/m^3 (1.83 ppm) (Alm *et al.*, 2001). This is 2.2 to 5.3 times higher that the SchoolAir weekly mean PEs. The result of an earlier study of PEs of children attending preschool centres to CO led by the same author revealed median PE exposures to CO in the range 0.9 to 2.0 mg/m^3 (0.79-1.75 ppm) (Alm *et al.*, 1994). These medians are comparable to the upper end of the SchoolAir weekly mean PEs. A study conducted in Oxford, UK, investigating adult personal exposures and microenvironment concentrations, resulted in mean CO personal exposure (mean of 38 individual samples) of 1.1 mg/m^3 (0.96 ppm), which is again comparable to the upper end of the SchoolAir results (Lai *et al.*, 2004). 48-hour mean PE of 50 office workers reported in a study conducted in Milan was 2.1 ppm, which is more than two times higher than the highest SchoolAir weekly mean PE (De Bruin *et al.*, 2004). However such direct comparison is inappropriate, as the averaging times are different.

4.2.3. Nitrogen dioxide (NO_2)

Overall nitrogen dioxide showed moderate variation. PEs were slightly (but with high statistical significance) higher than MEs, but lower than outdoor concentrations. This held true for all schools and rounds of measurements. These results contradict an Australian

school-based study which compared schools with unflued gas heating and flued gas or electric heating. The findings of that study were that mean personal exposures (measured with Palmes tubes) were lower than concentrations measured in classrooms or in the children's home kitchens - for both unflued gas heating and flued gas or electric heating sample groups (Pilotto *et al.*, 2004).

The results of the SchoolAir study show that using outdoor concentrations of NO_2 for exposure estimation would have been inappropriate, as this would overestimate personal exposures, which agrees with previously conducted studies (Ashmore and Dimitroulopoulou, 2009).

SchoolAir weekly means of modelled PEs were in the range from 47.6 to 57.9 ppb and were overall higher than the PE results of previous studies reviewed by the author. It should be noted that all the reviewed studies were using diffusion tubes to measure personal exposures. A study carried out in two schools in Southampton, UK, with 46 children providing at least one personal NO_2 sample (Linaker *et al.*, 1996) resulted in a weekly mean range of 10-80 $\mu g/m^3$ (5.3-42.5 ppb). Another PE study that was conducted in Southampton later was aimed at investigating relationships of PE to NO_2 and severity of asthma in children with the mean age of 10 years. The range of weekly mean PEs measured with Palmes tubes was 4.2-58.2 $\mu g/m^3$ (2.2-30.9 ppb), which is below the SchoolAir weekly means, although is comparable (Chauhan *et al.*, 2003). A Chilean study of children's personal exposures showed slightly higher mean PEs than the other reviewed studies with a mean of 88 personal samplers of 25.9 ppb, which is still about half of the SchoolAir weekly mean PEs (Rojas-Bracho *et al.*, 2002).

4.2.4. Total volatile organic compounds (TVOC)

In the summer round of measurements PEs to TVOC were slightly higher than relevant MEs, except for School S3 where PE and ME were almost equal. In the three out of four cases the mean difference between PE and ME was in the range from 0.06 to 0.1 ppm. This is generally in agreement with the results of a major American study, which showed that PEs measured with personal exposure monitors were higher than TVOC concentrations measured indoors in subjects' homes, however differences between PEs and MEs were larger in their case (Wallace *et al.*, 1991). The range of the SchoolAir modelled PEs are comparable to the results of Wallace *et al.* (1991), who reported a mean TVOC personal exposure of 2.9 mg/m^3 (or 0.95 ppm), which was a mean of 1500 individual PE samples, however their results were 2.6 to 4.5 times higher than the PE range in the SchoolAir study.

4.2.5. Formaldehyde (HCHO)

There was little difference between personal and measured exposures to formaldehyde. In schools R, S2 and S3 measured exposures were slightly higher than personal. This is in agreement with the results of a home-based study conducted in Sweden (Gustafson *et al.*, 2005), in which personal exposures with HCHO concentrations measured in bedrooms were compared. However, in School S1 PE was a little higher than ME. In all cases the mean difference was under 10 ppb (in the absolute value). The SchoolAir PE results are comparable to mean exposures measured with personal monitors – a portable pump with a sampling cartridge inside (Shinohara *et al.*, 2004). Their mean PEs were in the range 7-46 ppb, whereas the SchoolAir weekly mean PEs were 16-41 ppb. The SchoolAir results are also comparable to mean PE in the study by Gustafson *et al.* (2005) of 28 $\mu g/m^3$ (22.8 ppb), which was the mean of 63 individual personal samples. Their mean value is mid-range of the SchoolAir PE mean values. The SchoolAir results are in agreement with the results of direct PE measurements of 15 adults in Finland, where the 48-hour mean was 21.4 ppb (Jurvelin *et al.*, 2001).

4.2.6. Carbon dioxide (CO_2)

In most cases PEs to carbon dioxide were lower than exposures measured in classrooms, as classroom weekly mean concentrations were higher than those measured in other indoor locations or outdoors. Thus by changing their locations from classrooms to somewhere else within the school children lowered the CO_2 concentrations that they were exposed to. Winter PEs were overall the highest of the three rounds, if compared within each school (except for one class in School S3 for whom PE to CO_2 in the autumn was slightly higher than in the winter). As CO_2 is not considered to be an indoor air pollutant the author was not able to find the results of any previously conducted studies that would aim at measuring personal exposures to this gas. Thus no comparisons of the SchoolAir CO_2 PEs with previously published results are presented here.

4.2.7. Linear regression results

Linear regression models correlating estimated personal exposures (Class A) to measured concentrations (in Classroom A) suggested that in the majority of cases only a small proportion of personal exposures to NO_2, CO_2, PM and TVOC can be explained by MEs to relevant pollutants, i.e. most coefficients of determination for these air components were less than 0.5.

In an Indian school-based study personal exposures of pupils and staff to $PM_{0.5-10}$ were assessed using personal monitors (filter based, measuring particle mass concentrations in $\mu g/m^3$) (Gadkari, 2009). Personal exposures measured for each participant were then correlated with indoor and outdoor levels of PM_{10}. The coefficients of determination (R^2) for personal to indoor correlations were in the range 0.02-0.79 with 44 out of 52 coefficients being less than 0.5. Personal exposures of pupils and staff of three different schools were investigated, and the personal to indoor R^2 coefficients were higher for a school situated close to a steel plant and downwind from it. The range of $PM_{0.5-5.0}$ personal to indoor coefficients of determination in the SchoolAir study was 0.16 to 0.82, with 7 out of 11 calculated coefficients being under 0.5, which is comparable with the results of the Indian study.

The results of the linear regression between PE and ME for NO_2 contradict the results of a previously conducted home based study (Spengler *et al.*, 1994) which showed that 60% of the variation in personal exposure levels was explained by the variation in indoor level (measured in bedrooms). The SchoolAir results showed that only 9% to 39% of personal NO_2 exposure were explained by the classroom measurements. Higher R^2 values in Spengler's study might be explained by the fact that people spend more time in their bedrooms and at home in general, rather than at school, thus the bedroom levels might influence PEs more than those measured in classrooms. Another study also found that personal exposures were closely related to home indoor levels the range of the correlation coefficient (R) was 0.61-0.87, which mean the R^2 range of 0.37-0.76 (Quackenboss *et al.*, 1986).

For CO and HCHO the results of the linear regression were inconclusive, with about half of the cases resulting in $R^2 < 0.5$ and the other half – in $R^2 > 0.5$. No seasonal or school related patterns were observed for the coefficient of determination distribution for these two pollutants.

4.3. Comparison of measured and personal exposures with indoor air guidelines

Daily means of exposures measured from 8:45 to 15:30 each day with fixed monitors in three indoor locations in each school were compared to the mean 8- and 24-hour indoor air guidelines. The same was done for the daily means of modelled personal exposures of classes A and B.

The daily means for NO_2 were compared to the 24-hour indoor air guideline by Health Canada of 50 ppb (Health Canada), as no 8-hour mean indoor air guidelines for NO_2 were

found by the author. For CO the WHO 8-hour average indoor air guideline of 9 ppm was used (WHO, 2010). For HCHO – the Health Canada 8-hour average guideline of 0.04 ppm (Health Canada), and for CO_2 – the UK Department for Education and Employment Building Bulletin 101 guideline value of 1,500 ppm (average of a school day) (BB101, 2006) and the Health Canada 24-hour average of 3,500 ppm (Health Canada) were used.

The author did not find any 8-hour average indoor air guidelines for TVOC, therefore maximum acceptable concentrations guideline values were used. For the purpose of comparisons two different maximum acceptable values were taken: the Finnish Society of Indoor Air Quality and Climate guideline of 200 $\mu g/m^3$ and the Australian National Health and Medical Research Council guideline of 500 $\mu g/m^3$ (Ajiboye *et al.*, 2006). These values were compared with one minute averages recorded by the wireless gas monitors and numbers and percentages of observations exceeding these thresholds were calculated. In order to convert the guideline values expressed in $\mu g/m^3$ into ppm the same method was used as described in Section 4.1.4: for conversion purposes the average TVOC molecular weight of 75 gram/mole was taken. Thus 200 $\mu g/m^3$ became 0.0652 ppm and 500 $\mu g/m^3$ – 0.163 ppm.

No indoor air quality guideline expressing a PM guideline value in particle numbers rather than mass concentration was found by the author. Thus the SchoolAir results for $PM_{0.5-5.0}$ were not compared with any guidelines.

The results of the comparisons of exposures measured with fixed monitors in indoor locations with 8- and 24-hour average guidelines are presented in Table 27. The table shows the number and percentage of cases when daily means exceeded the guideline values. The total number of cases per school per season is 15, which is 3 indoors locations by 5 days of measurements in each round.

The results of modelled PEs comparisons with 8- and 24-hour average guideline values are presented in Table 28. In this table the total number of cases was 10 for suburban schools (2 classes by 5 days of measurement per round) and 5 cases for the rural school – 1 class by 5 days per round.

None of the daily means of either measured or modelled personal exposures to **CO** were found to exceed the 8-hour average guideline of 9 ppm.

For **NO_2** indoor daily mean MEs exceeded the 24-hour guideline value of 50 ppb in every school in all rounds of measurements. The percentages of ME daily means over the threshold were in the range from 13% to 67% out of total number of cases (15). For daily

means of PE to NO_2 the proportion of exceeding cases was even higher than for ME – 60%-80%, as there were less total cases and modelled PEs were in general higher than MEs. Caution should be taken when interpreting the results of this comparison, as the daily means were compared with 24-hour guideline. However, theses results indicate that further research in this area is required. For example, it would be useful to compare hourly means with the 1-hour WHO guideline of 110 ppb (WHO, 2010).

Some of indoor and personal exposure measurements exceeded the 8-hour average guideline value for **HCHO** of 0.04 ppm. Measurements conducted in School S2 did not result in any daily means exceeding the guideline, however, in the schools R and S3 13% of cases, and in School S1 one third of all cases exceeded the guideline. For PEs in schools R and S2 there were no cases exceeding the guideline value, in School S3 there was one case out of ten total and in School S1 half (5 cases) of the PE daily means exceeded the guideline.

In the majority of cases the school day guideline value of 1,500 ppm of **CO_2** was exceeded. For MEs the proportion of cases above the guideline was in the range from 13% to 67%, with an exception of School S2 in the autumn and summer rounds of measurements, where none of the cases exceeded the guideline. School S3 showed the highest proportion of indoor daily means above the threshold in the winter round (67%) and in the summer (47%) and the second highest in the autumn round (67%). Moreover, in the autumn and winter daily means of CO_2 concentrations measured in indoor locations in this school sometimes exceeded the 24-hour guideline of 3,500 ppm – in 5 (33%) cases and in 4 (24%) cases in each season respectively.

For PEs the proportions of daily means exceeding the 1,500 ppm guideline were in the range 20-100%, with the exception of School S2 in the autumn and summer, where all PE daily means were below the threshold. However, none of the daily mean PEs exceeded 3,500 ppm.

Table 29 and Table 30 present the results of **TVOC** one-minute averages with the two different guideline thresholds: of 200 $\mu g/m^3$ (0.0652 ppm) and 500 $\mu g/m^3$ (0.163 ppm), for measured and personal exposures. The tables show that the vast majority of both ME and PE observations exceeded the more strict maximum recommended value of 0.0652 ppm. For MEs the proportion of observations exceeding the threshold was in the range 48-100%, and for the majority of locations in each school 100% of observations exceeded the guideline (Table 29). For PEs this proportion was from 58% to 94% (Table 30). When the less strict guideline value of 0.163 ppm was taken, then the proportion of MEs exceeding

this threshold was in the range 16-100%, whereas 37-89% of all PE observations exceeded the guideline.

The results of the above comparisons are concerning and indicate that for the measured gases such as NO_2, HCHO, TVOC and CO_2 the indoor air quality in schools did not meet the guidelines. Modelled personal exposures also exceeded the recommended guideline values, suggesting that further investigation is needed.

4.4. Health questionnaire results

Preliminary health survey results revealed that less proportion of the rural school children showed any respiratory and/or allergic symptoms, than the children in the suburban schools investigated. It must be noted though that the populations investigated in this pilot study were small and that no proper analysis of the possible influence of personal exposures on health effects has been performed yet. It is envisaged that such detailed analysis and modelling might be performed in the future with the aim to publish the results in peer reviewed journals.

There was inconsistency of parental responses in the health part of the questionnaire: on some occasions parents / guardians reported that their child had not had a respiratory / allergic symptom *ever* in their life, but later along the questionnaire they would respond positively to a question about the same symptom *in the last 12 months*. For the purpose of this initial descriptive analysis the answers were kept as they were provided by the respondents.

4.5. Advantages of the proposed method of personal exposure estimation

The results of the pilot SchoolAir study showed that modelled personal exposures of schoolchildren were significantly different from the exposures measured with fixed monitors in home classrooms. This indicates that personal exposures to air pollutants should not be approximated to the measurements of one fixed monitor. Using readings of a fixed monitor may either underestimate or overestimate the real personal exposure, as it does not take in account exposures of children to air pollutants in any other micro-environments during the school day.

Although personal exposure monitoring using personal samplers allow detailed measurements and comparisons of the daily variation of exposure between individuals, usually there are problems with the limited number of samplers available as well as equipment failures (Alm *et al.*, 2000; Mejía *et al.*, 2011). The proposed method has an

advantage of using less equipment, but at the same time covering most of the school areas where children spend their time throughout the school day. Thus by using precise by-class time-activity-location records combined with the measurements at each location within the school, it is possible to get accurate estimations of children's personal exposures, which might closely reflect the true personal exposures.

In a bigger study it could be recommended to cover more / all microenvironments of each school – both indoors (such as "home" classrooms, computer rooms, art and music rooms, libraries, halls and corridors) and outdoors (the best solution would be to have multiple outdoor monitoring sites within the school grounds to investigate special variability of outdoor air quality nearby schools), as well as cover outside school microenvironments, such as home.

4.6. Limitations of the pilot study

In the duration of the pilot SchoolAir study a number of issues were observed that affected the outcomes. Below the limitations of the measuring equipment / technique and of the health and background questionnaire survey are described.

Measurements limitations

There were some equipment issues and failures during the data collection stage of the pilot SchoolAir study, such as wireless monitors system coverage issues, gas monitors calibration issues and failures of gas monitors and particle counters. To solve the wireless system problems it can be recommended that in any future project using the same wireless gas monitors additional routers should be used to strengthen the wireless network. It can be advised that all equipment should be re-calibrated by manufacturers before each round of measurements to ensure quality and comparability of measurements.

To improve the reliability of outdoor measurements the outdoor monitors should be placed into a made for purpose enclosure, built with inert materials, e.g. not made of plastic to avoid VOC emissions. Ideally, a special outdoor housing with a built in dehumidifier / heater should be used for particle counters in outdoor environments to avoid the influence of microscopic water droplets on particle counts being registered, as might have happened in School S3 in the winter round of the SchoolAir pilot study. Products with this facility have been advertised by companies such as Grimm Aerosol Technik GmbH & Co. KG (Grimm Aerosol Technik, 2011).

As only four sets of monitoring equipment were available for the pilot study, it was possible to conduct simultaneous measurements only in four different locations. For a

bigger study it may be recommended to use more monitoring stations, to cover more micro-environments within (such as computer rooms, art and music rooms, libraries, corridors and breakout rooms) and, possibly, outside school environments.

Health and background survey limitations

The response rate in the pilot SchoolAir study was low, in particular in one of the participating schools. Although certain attempts were made to engage pupils, parents / guardians and school personnel in the study, for one school they did not bring the expected result. One of the reasons might have been the low level of the English language competency among the parents / guardians of the children, which might have prevented them from answering the questionnaire. It may be recommended that in any future studies more efforts are made to engage the school staff, pupils and their parents / guardians.

5. Conclusion and recommendations

Variability of measured concentrations

The results of the pilot SchoolAir study showed important temporal and spatial variations in concentrations of certain air components. The most prominent variability was observed for $PM_{0.5-5.0}$ and CO_2, which revealed extensive daily and weekly variability, as well as variability of weekly means across schools and seasons.

Highest indoor $PM_{0.5-5.0}$ number concentrations were observed in the winter round of measurements in comparison with the autumn and summer. Outdoor $PM_{0.5-5.0}$ concentrations were lower in the rural school in comparison with the suburban schools. Outdoor-indoor relations of particle concentrations were different in the rural and suburban settings: in the rural school outdoor $PM_{0.5-5.0}$ concentrations were lower than indoors, whereas in the suburban schools outdoor concentrations were higher than these indoors.

Highest indoor CO_2 concentrations were observed in the winter round of measurements and the lowest – in the summer. This can be explained by the lack of ventilation in school rooms in the winter months. CO_2 weekly mean concentrations were lower in physical education and assembly halls rather than in classrooms.

Weekly mean CO concentrations did not reveal major variations. It was noticed, however that CO and HCHO levels were influenced by certain human activities indoors (e.g. CO and HCHO concentration increased when pupils / teachers were using white board markers and during art / painting lessons), however no further investigation of this was undertaken. In cases of both HCHO and CO outdoor mean concentrations were either lower then or similar to indoors, which can indicate that dominating sources were indoors (note that only the summer measurements were available for HCHO).

NO_2 weekly means revealed limited variability, but in case of all schools and all seasons indoors concentrations were lower than outdoor, which indicate that major sources of NO_2 were outdoors (e.g. vehicular emissions).

Summer measurements of TVOC did not reveal any obvious school specific patterns – sometimes outdoor concentrations were lower then indoors, whereas in other schools it was approximately at the same level or higher. Indoor concentrations of TVOC were influenced by indoor activities, such as art lessons. On hotter days the outdoor concentrations may have been influenced by TVOC emissions from the plastic cover of the outdoor monitoring station.

The results of the study showed that measured indoor concentrations and modelled personal exposures to such gases as NO_2, HCHO, TVOC and CO_2 exceeded the recommended indoor air guidelines. Besides, comparisons with previously conducted studies revealed that at the levels comparable to the ones recorded in the SchoolAir study some adverse respiratory health effects had been observed – especially for NO_2, HCHO and TVOC. These findings suggest that the health of children attending the investigated schools may be at risk.

Personal exposures

Personal exposures (PE) of one to two classes per school were modelled and then PEs of one class were compared to the measured exposures (ME) in the relevant "home" classroom of each class.

In case of particulate matter, NO_2 and TVOC it was found that weekly mean PEs were higher than MEs in the majority of cases. For $PM_{0.5-5.0}$ nine out of eleven comparison cases resulted in statistically significant difference with PE higher than ME, for NO_2 all eleven pairs were significantly different, and for TVOC three out of four were significantly different.

For CO, HCHO and CO_2 most of the calculated weekly mean PEs were lower than relevant MEs. For CO in 8 out of 11 cases PE were lower than ME and the results were of a high statistical significance. For HCHO it was in 3 out of 4 cases and for CO_2 – in 8 out of 11 cases.

These results show that in both cases, whether PEs were significantly higher or lower than MEs, it would have been inappropriate to use the measurements of fixed monitors located in a "home" classroom as a proxy of children's personal exposures at school.

The calculated changes in the coefficients of variation (CV) between weekly means of measured and personal exposures revealed that variability of modelled PE was higher than that of relevant ME. In the majority of cases (30 out of 52) the change in CV was positive and was equal to or exceeded 20%. Moreover, in 11 out of 52 cases this change exceeded 50%. Thus modelled PE seems to reflect more of the actual variability of exposures that children had during their days at school than exposures measured in a classroom, which is important when assessing exposure and health relationships.

The results of linear regression of personal exposures to measured exposures showed that for the three of the six investigated indoor air components – $PM_{0.5-5.0}$, NO_2, and CO_2 – only smaller proportions of the PEs could be explained by the relevant MEs (i.e. less then 50%).

For the other three pollutants – CO, HCHO and TVOC the results of linear regression were inconclusive, as half of the calculated coefficients of determinations were above 0.5 and the other half were below 0.5 (note that in case of HCHO and TVOC only the data from the summer round of measurements were available).

Health survey results:

Preliminary analysis of the health survey results revealed that there were variations of respiratory and allergic symptoms prevalence between the investigated schools – in some schools the prevalence rates were higher than in the others. Variations in the means of modelled personal exposures were observed as well. It has been observed that the children in one of the suburban schools, where the modelled yearly mean PEs were in the upper end of the inter-school yearly means range had the highest proportion of respiratory and allergic symptoms, whereas in the rural school the yearly means of modelled PEs were overall in the lower end of the inter-school yearly means range, and the rural school children had the lowest prevalence of symptoms. Thus the preliminary findings suggest that personal exposures to air pollutants in school environments may influence respiratory health of the children attending them. Further data analyses and additional research is required within the SchoolAir study to quantify the relationships between indoor air quality, personal exposures and prevalence of respiratory and allergic symptoms in school children of the participating schools.

Recommendations for further analysis of the data set collected in the pilot SchoolAir study

Due to the time constraints of this MPhil project it was not possible to perform all data analyses and modelling that would be beneficial to understand various pollutant interactions and health effects better, e.g. to study the influence of outdoor concentrations of pollutants on the indoor concentrations, to investigate different pollutant interactions, etc.

It may be recommended therefore that in the future the following modelling and data analysis would be performed:

- To calculate indoor to outdoor concentration ratios – I/O ratios – for all pollutants in all schools and for all rounds of measurements, in order to explore whether a

pollutant was generated mostly outdoors or indoors, and to look for any seasonal or spatial differences.

- To look into differences / similarities of measured exposures in the pairs of classrooms in suburban schools – Classroom A *vs.* Classroom B.
- To compare modelled PEs to the measured exposures for Class B the same way it was done in this sub-study for Class A – for the suburban schools. The next step would be to compare the modelled PEs of Class A with the modelled PEs of Class B within each school.
- To conduct in-depth analysis of the health survey results – by individual symptom and groups of symptoms, and to perform multivariate analysis to investigate which indoor air pollutants may influence the respiratory health of school children the most.

Recommendations for any future larger studies resulting from the SchoolAir pilot study

Some recommendations can be drawn from the results and lessons learnt from the pilot stage of the SchoolAir study.

To describe the distribution of particle sizes and number concentrations more precisely and to allow direct comparisons with previously conducted studies, it can be recommended to acquire new sets of particle counters, which would allow to measure particle number concentrations in the fine and ultra fine particle size range (e.g. with narrower particle size ranges measured).

To minimise equipment failures and calibration issues, all the instruments used should be send to the manufacturers for re-calibration before each round of measurements.

In a bigger study it can be recommended that more within and outside the school microenvironments are covered by measurements, such as rooms of various use within the school (classrooms of different primary year classes, computer rooms, art and music rooms, libraries, halls, corridors and canteens), home environments (bedrooms, living rooms, and kitchens), as well as outdoors environments surrounding schools and homes. Thus it would be possible to model personal exposures of children to air pollutants more precisely.

In order to improve health questionnaire response rate it may be recommended to work closer with the school staff, children and children's parents (e.g. by conducting explanatory

talks to children, staff and parents regarding the aims and importance of the air quality and health study, as well as giving general scientific talks and presentation to the children as part of their science lessons). The SchoolAir research team had several successful talks with the children and teachers of some of the participating schools as well as in one school which was outside the pilot project. The participating schools where the staff and children showed more interest in this scientific project showed higher response rates. However, in other schools, which showed low response rate, the researchers probably should have been more diligent in their approach to communicate the importance of the study to the teachers in particular who were the vital link between the researchers and children's parents / guardians.

It may be recommended to translate the questionnaire and any accompanying supplementary materials into relevant foreign languages in case of multi-cultural schools. This would allow parents / guardians with insufficient competence of the English language to understand the questions and complete the questionnaire. Preceding consultations with the headmasters of such schools would be beneficial. Other methods should be considered to improve uptake of the survey. One of the ways may be to perform several rounds of questionnaire distribution in order to give non-responders more chances to fill in the health questionnaire.

Overall the proposed methodology of assessment of children's personal exposure to air pollutants during a school day provides an alternative to using personal exposure monitors. Whereas studies using personal exposure monitors are limited by the number of monitors available, as well as are usually affected by multiple equipment failures, the proposed method of combining measurements with stationary monitors in school microenvironments with the children's time-activity-location patterns can be a less expensive method allowing to accurately assess personal exposures of groups of children (e.g. classes or primary year groups). Moreover, the results of the pilot SchoolAir study showed that the majority of modelled personal exposures were significantly different from the exposures measured in "home" classrooms.

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7. Figures and tables

Table 3 Schedule of measurements at schools throughout the 2009/2010 school year

	ROUND 1 (Schools: R, S1, S2, S3)	**ROUND 2 (Schools: S1, S2, S3)**	**ROUND 3 (Schools: R, S1, S2, S3)**
Timing:	Sept-Nov, 2009 (5 days in each school)	Jan-Feb, 2010 (5 days in each school)	May-June, 2010 (5 days in each school)
Actions:	1) Health Questionnaire 2) Exposure Assessment 3) CO breath test	Exposure Assessment	1) Exposure Assessment 2) CO breath test

Table 4: Study population characteristics

School	**Target popu-lation**	**Children with returned questionnaires**		**Age**			**Gender**			
		Number	**% of target population**	**No. of questionnaires with age data**	**% of target population**	**Mean (SD), years**	**No. of questionnaires with gender data**	**% of target population**	**Female - No. (% of questionnaires with gender data)**	**Male - No. (% of questionnaires with gender data)**
R	102	58	56.9%	57	55.9%	7.63 (1.52)	58	56.9%	29 (50.0%)	29 (50.0%)
S1	90	54	60.0%	54	60.0%	7.54 (0.43)	54	60.0%	26 (48.1%)	28 (51.9%)
S2	87	44	50.6%	43	49.4%	7.7 (0.31)	44	50.6%	25 (56.8%)	19 (43.2%)
S3	89	11	12.4%	11	12.4%	7.55 (0.33)	11	12.4%	5 (45.5%)	6 (54.5%)
All schools	368	167	45.4%	165	44.8%	7.61 (0.94)	167	45.4%	85 (50.9%)	82 (49.1%)

Table 5: Monitoring station locations

	Location A	Location B	Location C	Location D (outdoors)	Location E
School R	Classroom A	Corridor (joining classrooms with the hall)	Hall	Playground	-
School S1	Classroom A	Classroom B	Hall	Playground	-
School S2	Classroom A	Classroom B	Hall	Playground	Canteen (a stand alone building) Measurements were performed on one day after the winter round of main measurements and were used for personal exposure modelling of S2 children in all three rounds (to represent the time children spent in the canteen).
School S3	Classroom A	Classroom B	Hall	Playground	-

Notes:
In schools R, S1 and S3 children had their lunch either in the assembly/physical education hall or in their home classrooms, whereas in school S2 there was a stand alone canteen building where children had their meals.

Table 6 Missing values for measured exposures (as % of total number of observations during the occupied part of the day – 8:45 to 15:30, over five days of measurements)

		PM(0.5-5.0)				CO				NO2				TVOC ‡				HCHO ‡				CO2			
		R*	S1	S2	S3	R*	S1 ¶	S2	S3 ¶	R*	S1 ¶	S2	S3 ¶	R*	S1	S2	S3	R*	S1	S2	S3	R*	S1 ¶	S2	S3 ¶
Autumn	Classroom A	1.1%	0.9%	0.6%	0.8%	1.1%	8.4%	1.2%	8.5%	1.1%	8.4%	1.2%	8.5%	–	–	–	–	–	–	–	–	1.1%	8.4%	1.2%	8.5%
	Classroom B / Corridor*	0.6%	– **	0.3%	0.6%	0.9%	8.3%	1.2%	9.8%	1.0%	8.3%	1.2%	9.8%	–	–	–	–	–	–	–	–	1.0%	8.3%	1.2%	9.8%
	Hall	60.7% §	1.1%	0.5%	6.3%	1.1%	16.6%	1.2%	19.6%	1.1%	16.6%	1.2%	19.6%	–	–	–	–	–	–	–	–	1.1%	16.6%	1.2%	19.6%
	Outdoors	3.4%	20.8% ¤	0.8%	20.5% †	3.1%	11.5%	1.2%	23.2%	3.1%	11.4%	1.2%	23.2%	–	–	–	–	–	–	–	–	3.1%	11.4%	1.2%	23.2%
Winter	Classroom A	–	0.4%	0.3%	0.7%	–	0.1%	0.5%	5.5%	–	0.1%	0.5%	5.5%	–	–	–	–	–	–	–	–	–	0.1%	0.5%	5.5%
	Classroom B / Corridor*	–	0.3%	0.5%	0.7%	–	4.3%	0.5%	22.1%	–	4.3%	0.5%	22.2%	–	–	–	–	–	–	–	–	–	4.3%	0.5%	22.2%
	Hall	–	0.6%	0.7%	0.9%	–	21.6%	0.6%	7.6%	–	21.6%	0.6%	7.6%	–	–	–	–	–	–	–	–	–	21.6%	0.6%	7.6%
	Outdoors	–	7.6%	0.4%	9.7%	–	11.9%	0.5%	12.5%	–	11.9%	0.5%	12.5%	–	–	–	–	–	–	–	–	–	11.9%	0.5%	12.5%
	Canteen ††	–	–	3.4%	–	–	–	5.0%	–	–	–	5.0%	–	–	–	–	–	–	–	–	–	–	–	5.0%	–
Summer	Classroom A	1.0%	0.5%	1.5%	2.4%	0.6%	4.4%	0.3%	2.2%	0.6%	4.4%	0.3%	2.3%	0.6%	4.4%	0.3%	2.2%	0.6%	3.9%	0.3%	1.0%	0.6%	4.4%	0.3%	2.2%
	Classroom B / Corridor*	0.6%	0.4%	0.3%	1.5%	1.8%	3.6%	0.3%	1.1%	0.6%	3.6%	0.3%	1.1%	0.6%	3.6%	0.3%	1.1%	0.6%	3.3%	0.3%	0.8%	0.6%	3.6%	0.4%	1.1%
	Hall	1.0%	0.4%	8.4%	1.5%	0.7%	4.0%	0.3%	3.4%	0.6%	4.0%	0.3%	3.4%	0.6%	4.0%	0.3%	3.3%	0.7%	3.6%	0.3%	2.5%	0.6%	4.0%	0.3%	3.4%
	Outdoors	0.7%	0.5%	19.8%	0.9%	1.2%	4.7%	0.3%	4.9%	1.2%	4.4%	0.3%	4.9%	1.2%	4.4%	0.3%	4.9%	1.0%	3.4%	0.3%	1.9%	1.4%	4.4%	0.3%	4.9%

Notes:

* School R was included into two rounds of measurements only (autumn and summer), due to logistic reasons.

In School R the measurements were conducted only in one classroom (A), as due to small size of classes all Primary 3 and 4 children were located in one classroom. The second monitoring station was located in a corridor connecting several classes with hall.

** $PM_{0.5-5.0}$ measurements for classroom B in School S1 in autumn are not presented due to equipment failure.

§ $PM_{0.5-5.0}$ measurements for hall in School R in autumn are available for 3 full days only (Mon-Wed), due to equipment failure.

¤ Outdoor $PM_{0.5-5.0}$ measurements in School S1 in autumn were not performed on one day of the week due to weather conditions.

† Outdoor $PM_{0.5-5.0}$ measurements in School S3 in autumn are missing for one day due to equipment failure.

¶ Due to connectivity issues with wireless gas monitors in Schools S2 and S3 during the autumn and winter rounds of measurements, for some locations gas concentrations were not recorded by the computer every minute (as it should) but were recorded more irregularly – with occasional gaps of 2 to 10 minutes. This still can be considered as continuous measurement. The problem was resolved in the summer round of measurements with installation of two additional wireless routers, which strengthened the network.

‡ Measurements of TVOC and HCHO concentrations taken during the autumn and winter rounds of measurements were discarded due to sensor calibration issues.

†† Exposures measured in a canteen were performed in School S2 in the winter round of measurements only.

Table 7 Missing values for modelled personal exposures of school classes (as % of total number of observations during the occupied part of the day – 8:45 to 15:30, over five days of measurements)

		PM(0.5.-5.0)				CO				NO2			
Season	**Class**	**R***	**S1**	**S2**	**S3**	**R***	**S1**	**S2**	**S3**	**R***	**S1**	**S2**	**S3**
Autumn	**A**	2.1%	0.6%	3.8%	6.9%	1.1%	3.6%	4.2%	20.0%	1.1%	3.6%	4.2%	20.0%
	B	–	0.6%	1.0%	1.1%	–	3.7%	1.2%	15.1%	–	3.7%	1.2%	15.1%
Winter	**A**	–	3.1%	0.2%	16.7%	–	6.0%	0.5%	7.8%	–	6.0%	0.5%	7.8%
	B	–	3.2%	2.8%	20.3%	–	7.6%	2.8%	32.7%	–	7.6%	2.8%	32.7%
Summer	**A**	0.6%	3.0%	3.2%	1.4%	0.6%	6.9%	2.6%	3.0%	0.6%	6.8%	2.6%	3.0%
	B	–	0.6%	0.3%	1.3%	–	3.9%	0.3%	2.5%	–	3.8%	0.3%	2.6%
		HCHO ‡				**TVOC ‡**				**CO2**			
Season	**Class**	**R***	**S1**	**S2**	**S3**	**R***	**S1**	**S2**	**S3**	**R***	**S1**	**S2**	**S3**
Autumn	**A**	–	–	–	–	–	–	–	–	1.1%	3.6%	4.2%	20.0%
	B	–	–	–	–	–	–	–	–	–	3.7%	1.2%	15.1%
Winter	**A**	–	–	–	–	–	–	–	–	–	6.0%	0.5%	7.8%
	B	–	–	–	–	–	–	–	–	–	7.6%	2.8%	32.7%
Summer	**A**	0.6%	6.2%	2.6%	1.4%	0.6%	6.8%	2.6%	3.0%	0.7%	6.8%	2.6%	3.0%
	B	–	3.4%	0.3%	1.3%	–	3.8%	0.3%	2.5%	–	3.8%	0.3%	2.5%

Notes: High percentage of missing values for some classes are due to children going to locations where exposure monitoring was not conducted, and when the missing measurements could not be substituted with any available measurements (e.g. children gong to a swimming pool for School S3).

* School R was included into two rounds of measurements only (autumn and summer), due to logistic reasons.

In School R the measurements were conducted only in one classroom, and consequently personal exposure was modelled for one class only (A), as School R had one composite class combining primary years 3 and 4.

‡ Measurements of TVOC and HCHO concentrations taken during the autumn and winter rounds of measurements were discarded due to sensor calibration issues.

Table 8 Erroneously high concentrations of outdoor $PM_{0.5-5.0}$ measured in the winter round in School S3

Day	Mean (particles/L)	SD (particles/L)	Mean exceeded overall Outdoor PM mean 1 by times:	Mean exceeded overall Outdoor PM mean 2 by times:
Monday	1,381,738	983,561	12	107
Tuesday	1,103,555	373,430	9	85
Wednesday	1,675,363	716,791	14	130
Thursday	2,141,490	839,404	18	166
Friday	12,847	5,009	n/a	n/a
Outdoor PM mean 1 (across all schools and all rounds, including winter measurements in School S3)	**116,704**	**438,178**		
Outdoor PM mean 2 (across all schools and all rounds, but *excluding* winter measurements in School S3)	**12,929**	**17,548**		

Table 9 Descriptive statistics – $PM_{0.5-5.0}$ (measured exposure), particles/L

Season	Location	School R*								School S1							
		N obs	Mean	SD	Median	Q1	Q3	GM	GSD	N obs	Mean	SD	Median	Q1	Q3	GM	GSD
Autumn	Classroom A	2,007	5,560	2,595	4,747	3,606	7,265	5,037	1.55	2,012	6,372	2,302	6,577	4,499	8,006	5,913	1.50
	Classroom B / Corridor*	2,018	4,796	2,134	3,883	3,285	6,495	4,396	1.50	– †	–	–	–	–	–	–	–
	Hall	798	5,382	3,077	4,031	3,203	6,613	4,715	1.63	2,007	6,072	2,601	6,249	3,879	7,811	5,422	1.66
	Outdoors	1,960	4,387	2,578	3,250	2,799	4,674	3,834	1.63	1,608	15,097	16,329	8,351	6,637	15,254	10,076	2.32
Winter	Classroom A	–	–	–	–	–	–	–	–	2,021	6,309	2,944	5,574	4,403	7,522	5,808	1.48
	Classroom B / Corridor*	–	–	–	–	–	–	–	–	2,023	5,637	3,167	4,682	3,878	6,636	5,062	1.54
	Hall	–	–	–	–	–	–	–	–	2,017	5,630	4,073	4,507	3,389	5,950	4,762	1.71
	Outdoors	–	–	–	–	–	–	–	–	1,875	12,519	13,613	6,896	4,510	14,150	8,567	2.23
Summer	Classroom A	2,009	5,111	1,627	5,157	3,819	6,118	4,847	1.39	2,019	8,422	5,424	6,313	4,425	11,906	6,896	1.89
	Classroom B / Corridor*	2,017	4,010	1,259	3,763	2,993	4,904	3,823	1.36	2,021	8,140	5,217	6,249	4,479	10,434	6,768	1.83
	Hall	2,009	4,583	1,859	4,619	3,039	5,710	4,219	1.51	2,022	6,178	3,554	5,246	3,407	7,438	5,312	1.72
	Outdoors	2,016	3,943	2,629	3,206	2,521	4,993	3,447	1.61	2,019	13,117	12,100	7,177	4,073	17,940	8,610	2.52
Season	Location	School S2								School S3							
		N obs	Mean	SD	Median	Q1	Q3	GM	GSD	N obs	Mean	SD	Median	Q1	Q3	GM	GSD
Autumn	Classroom A	2,018	5,265	2,223	4,698	3,989	5,640	4,932	1.40	2,014	6,708	2,388	6,251	5,409	7,293	6,398	1.34
	Classroom B	2,023	5,184	1,830	4,738	4,093	5,702	4,922	1.36	2,017	8,373	3,229	7,632	5,948	10,220	7,784	1.47
	Hall	2,019	5,764	2,348	5,250	4,115	6,656	5,377	1.43	1,903	10,207	5,902	8,574	6,140	11,689	8,810	1.71
	Outdoors	2,013	6,970	6,473	4,982	3,774	6,601	5,628	1.75	1,613	12,225	12,251	8,696	7,217	15,040	9,619	1.93
Winter	Classroom A	2,024	17,598	11,473	20,308	6,971	26,499	13,087	2.34	2,016	6,794	3,121	6,639	4,432	8,048	6,171	1.56
	Classroom B	2,020	15,867	9,642	17,934	6,878	24,620	12,232	2.21	2,016	3,936	1,486	3,770	2,946	4,731	3,677	1.45
	Hall	2,016	19,759	12,808	23,190	7,050	32,076	14,241	2.48	2,012	10,404	5,190	9,612	6,008	14,169	9,048	1.74
	Outdoors	2,022	41,584	30,030	48,749	9,657	65,401	24,984	3.42	1,834	1,178,559 ¶	957,138	965,915	588,940	1,797,320	467,782	7.42
	Canteen ‡	115	4,554	921	4,459	3,836	5,195	4,465	1.22	–	–	–	–	–	–	–	–
Summer	Classroom A	1,999	5,373	4,037	3,753	2,662	6,412	4,367	1.83	1,981	5,910	3,636	4,805	3,145	7,263	5,004	1.77
	Classroom B	2,023	5,022	2,918	4,095	2,858	6,512	4,375	1.66	2,000	5,389	2,195	5,411	3,727	6,692	4,899	1.58
	Hall	1,860	6,582	5,106	4,501	2,978	7,876	5,231	1.90	1,999	6,463	2,905	5,749	4,342	8,975	5,769	1.65
	Outdoors	1,628	11,038	11,454	7,098	2,404	14,935	6,612	2.78	2,011	7,850	8,590	5,964	2,649	8,144	5,318	2.35

Notes: N obs – Number of valid observations.
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile
GM – Geometric mean
GSD – Geometric standard deviation

* In School R exposure measurements were conducted in one classroom only, as the school had one composite class combining primary years 3 and 4. The second monitoring station was placed in a corridor connecting several classrooms.
No measurements were conducted in School R in the winter round due to logistic reasons.

† $PM_{0.5-5.0}$ measurements for classroom B in School S1 during the autumn round are not presented due to equipment failure.

‡ Measurements in Canteen in School S2 were conducted in the winter round only.

¶ Outdoors $PM_{0.5-5.0}$ measurements in the winter round in School S3 (Monday-Thursday) were discarded from PE estimation, due to erroneously high values recorded.

Table 10 Descriptive statistics – $PM_{0.5\text{-}5.0}$ (measured exposure). Geometric mean (GM) and geometric standard deviation (GSD), particles/cm^3

Season	Location	R		S1		S2		S3	
		GM	GSD	GM	GSD	GM	GSD	GM	GSD
Autumn	Classroom A	5.0	1.6	5.9	1.5	4.9	1.4	6.4	1.3
	Classroom B /Corridor	4.4	1.5	–	–	4.9	1.4	7.8	1.5
	Hall	4.7	1.6	5.4	1.7	5.4	1.4	8.8	1.7
	Outdoors	3.8	1.6	10.1	2.3	5.6	1.7	9.6	1.9
Winter	Classroom A	–	–	5.8	1.5	13.1	2.3	6.2	1.6
	Classroom B /Corridor	–	–	5.1	1.5	12.2	2.2	3.7	1.5
	Hall	–	–	4.8	1.7	14.2	2.5	9.1	1.7
	Outdoors	–	–	8.6	2.2	25.0	3.4	–	7.4
	Canteen	–	–	–	–	4.5	1.2	–	–
Summer	Classroom A	4.8	1.4	6.9	1.9	4.4	1.8	5.0	1.8
	Classroom B /Corridor	3.8	1.4	6.8	1.8	4.4	1.7	4.9	1.6
	Hall	4.2	1.5	5.3	1.7	5.2	1.9	5.8	1.6
	Outdoors	3.4	1.6	8.6	2.5	6.6	2.8	5.3	2.3

Notes: For number of observations and general notes see notes for Table 9.

Table 11 Descriptive statistics – CO (measured exposure), ppm

Season	Location	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	Classroom A	2,007	1.03	1.10	0.65	0.41	1.30	1,859	0.90	0.55	0.70	0.50	1.14
	Classroom B / Corridor*	2,010	0.58	0.48	0.47	0.21	0.75	1,861	0.99	0.57	0.92	0.47	1.39
	Hall	2,008	0.43	0.19	0.38	0.31	0.51	1,693	0.50	0.16	0.49	0.36	0.62
	Outdoors	1,968	0.39	0.05	0.39	0.36	0.42	1,797	0.41	0.10	0.37	0.34	0.45
Winter	Classroom A	–	–	–	–	–	–	2,028	0.77	0.40	0.67	0.51	0.86
	Classroom B / Corridor*	–	–	–	–	–	–	1,943	0.78	0.45	0.75	0.39	1.08
	Hall	–	–	–	–	–	–	1,591	0.30	0.09	0.28	0.24	0.33
	Outdoors	–	–	–	–	–	–	1,789	0.28	0.08	0.27	0.22	0.33
Summer	Classroom A	2,018	0.52	0.17	0.49	0.39	0.64	1,940	0.67	0.40	0.55	0.39	0.81
	Classroom B / Corridor*	1,994	0.22	0.22	0.15	0.06	0.36	1,957	0.66	0.57	0.42	0.23	0.94
	Hall	2,016	0.36	0.08	0.34	0.30	0.40	1,949	0.45	0.14	0.42	0.37	0.49
	Outdoors	2,006	0.29	0.11	0.25	0.22	0.31	1,935	0.48	0.23	0.47	0.40	0.57
Season	Location	School S2						School S3					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	Classroom A	2,005	0.46	0.09	0.44	0.39	0.53	1,858	0.74	0.25	0.74	0.55	0.90
	Classroom B	2,005	0.29	0.15	0.25	0.18	0.37	1,832	0.65	0.21	0.65	0.49	0.81
	Hall	2,005	0.38	0.08	0.38	0.32	0.43	1,632	0.55	0.24	0.50	0.38	0.71
	Outdoors	2,005	0.43	0.06	0.42	0.38	0.47	1,560	0.47	0.28	0.41	0.26	0.54
Winter	Classroom A	2,019	0.62	0.18	0.60	0.50	0.73	1,918	0.88	0.25	0.81	0.69	1.11
	Classroom B	2,019	0.59	0.31	0.52	0.34	0.79	1,580	1.03	0.30	1.03	0.84	1.23
	Hall	2,017	0.46	0.14	0.44	0.35	0.56	1,876	0.55	0.17	0.53	0.44	0.63
	Outdoors	2,019	0.47	0.09	0.49	0.39	0.54	1,776	0.47	0.18	0.41	0.33	0.60
	Canteen ‡	113	0.58	0.16	0.60	0.47	0.68	–	–	–	–	–	–
Summer	Classroom A	2,024	0.46	0.10	0.44	0.39	0.54	1,985	0.58	0.19	0.57	0.46	0.66
	Classroom B	2,023	0.31	0.17	0.25	0.20	0.33	2,008	0.39	0.18	0.39	0.24	0.53
	Hall	2,024	0.40	0.11	0.37	0.33	0.49	1,960	0.46	0.13	0.45	0.37	0.52
	Outdoors	2,023	0.50	0.17	0.47	0.43	0.55	1,931	0.50	0.11	0.46	0.43	0.52

Notes:
N obs – Number of valid observations.
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

* In School R exposure measurements were conducted in one classroom only, as the school had one composite class combining primary years 3 and 4. The second monitoring station was placed in a corridor connecting several classrooms.

No measurements were conducted in School R in the winter round due to logistic reasons.

‡ Measurements in Canteen in School S2 were conducted in the winter round only.

Table 12 Descriptive statistics – NO_2 (measured exposure), ppb

Season	Location	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	Classroom A	2,007	49.8	5.6	50.0	46.0	53.0	1,859	51.5	6.8	52.0	48.0	56.0
	Classroom B / Corridor*	2,010	44.4	5.0	45.0	41.0	48.0	1,861	43.5	4.6	44.0	41.0	47.0
	Hall	2,008	46.1	4.6	46.5	44.0	49.0	1,693	50.2	7.1	49.0	45.0	55.0
	Outdoors	1,968	56.9	4.6	57.0	54.0	60.0	1,799	66.7	6.5	67.0	62.0	71.0
Winter	Classroom A	–	–	–	–	–	–	2,028	48.9	7.0	50.0	45.0	53.0
	Classroom B / Corridor*	–	–	–	–	–	–	1,943	41.6	4.4	43.0	39.0	45.0
	Hall	–	–	–	–	–	–	1,592	46.4	5.4	45.0	43.0	51.0
	Outdoors	–	–	–	–	–	–	1,789	62.9	3.1	63.0	60.0	65.0
Summer	Classroom A	2,018	46.1	6.0	46.0	42.0	50.0	1,940	51.5	8.3	52.5	47.0	57.0
	Classroom B / Corridor*	2,018	45.5	6.6	45.0	41.0	50.0	1,957	43.9	6.4	43.0	40.0	48.0
	Hall	2,017	48.5	4.9	48.0	45.0	52.0	1,949	48.5	5.8	48.0	44.0	52.0
	Outdoors	2,006	63.8	6.0	64.0	60.0	67.0	1,941	63.4	6.6	64.0	59.0	68.0
Season	Location	School S2						School S3					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	Classroom A	2,005	55.8	5.4	55.0	52.0	58.0	1,858	47.6	5.0	48.0	46.0	50.0
	Classroom B	2,005	50.6	5.9	49.0	47.0	54.0	1,832	43.0	4.8	43.0	41.0	45.0
	Hall	2,005	52.4	6.5	51.0	48.0	55.0	1,633	49.3	7.0	49.0	45.0	54.0
	Outdoors	2,005	67.6	7.4	66.0	63.0	71.0	1,560	71.1	8.2	69.0	65.0	75.0
Winter	Classroom A	2,019	51.4	4.1	51.0	48.0	54.0	1,918	54.1	5.1	55.0	52.0	57.0
	Classroom B	2,019	44.7	4.2	44.0	42.0	47.0	1,580	39.5	6.4	40.0	35.0	44.3
	Hall	2,018	48.8	4.4	49.0	46.0	51.0	1,876	52.8	8.2	52.0	48.0	57.0
	Outdoors	2,019	66.5	5.0	66.0	64.0	70.0	1,776	71.8	5.2	71.0	68.0	76.0
	Canteen †	113	59.1	10.6	59.0	51.0	67.0	–	–	–	–	–	–
Summer	Classroom A	2,024	52.0	7.1	52.0	46.0	56.0	1,983	51.4	8.7	51.0	47.0	56.0
	Classroom B	2,023	45.0	6.6	44.0	41.0	48.0	2,007	42.1	6.7	43.0	39.0	46.0
	Hall	2,024	56.1	5.9	56.0	52.0	61.0	1,961	53.1	6.4	52.0	49.0	57.0
	Outdoors	2,024	70.2	7.8	72.0	65.0	76.0	1,931	69.3	6.0	70.0	65.0	74.0

Notes: Measurements in this table are expressed in ppb (rather than ppm).
N obs – Number of valid observations.
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

* In School R exposure measurements were conducted in one classroom only, as the school had one composite class combining primary years 3 and 4. The second monitoring station was placed in a corridor connecting several classrooms.
No measurements were conducted in School R in the winter round due to logistic reasons.
† Measurements in Canteen in School S2 were conducted in the winter round only.

Table 13 Descriptive statistics – TVOC (measured exposure), ppm

Season	Location	School R						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	Classroom A	2,018	0.19	0.05	0.18	0.15	0.22	1,940	0.11	0.13	0.06	0.05	0.12
	Classroom B / Corridor*	2,018	0.20	0.07	0.18	0.16	0.21	1,957	0.15	0.07	0.11	0.10	0.18
	Hall	2,017	0.72	0.32	0.62	0.49	0.85	1,949	0.28	0.16	0.22	0.17	0.38
	Outdoors	2,006	0.18	0.24	0.10	0.06	0.19	1,941	0.26	0.36	0.07	0.04	0.30
Season	Location	School S2						School S3					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	Classroom A	2,024	0.19	0.08	0.18	0.13	0.26	1,985	0.24	0.15	0.23	0.13	0.31
	Classroom B	2,023	0.32	0.06	0.32	0.27	0.37	2,008	0.35	0.16	0.35	0.27	0.48
	Hall	2,024	0.44	0.18	0.44	0.31	0.57	1,962	0.28	0.11	0.25	0.19	0.35
	Outdoors	2,024	0.60	0.47	0.60	0.11	1.00	1,931	0.13	0.19	0.06	0.03	0.12

Notes:

N obs – Number of valid observations.
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

Measurements of TVOC and HCHO concentrations taken during the autumn and winter rounds of measurements were discarded due to sensor calibration issues.

* In School R exposure measurements were conducted in one classroom only, as the school had one composite class combining primary years 3 and 4. The second monitoring station was placed in a corridor connecting several classrooms.
‡ Measurements in Canteen in School S2 were conducted in the winter round only.

Table 14 Descriptive statistics – HCHO (measured exposure), ppb

Season	Location	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	Classroom A	2,018	33.6	23.7	29.0	22.0	39.0	1,950	36.5	72.1	5.0	1.0	32.0
	Classroom B / Corridor*	2,018	14.2	22.4	8.0	3.0	17.0	1,963	41.9	62.8	10.0	2.0	51.0
	Hall	2,016	24.2	26.0	18.0	13.0	26.0	1,956	27.2	16.9	27.0	18.0	44.0
	Outdoors	2,009	2.8	3.0	1.0	1.0	4.0	1,961	5.5	5.1	4.0	1.0	9.0
Season	**Location**	**School S2**						**School S3**					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	Classroom A	2,024	17.6	13.5	16.0	2.0	28.0	2,010	30.2	29.4	32.0	1.0	43.0
	Classroom B	2,024	18.8	12.6	21.0	7.0	29.0	2,013	23.5	21.1	20.0	1.0	43.0
	Hall	2,024	16.8	10.2	16.0	10.0	24.0	1,979	29.8	29.8	19.0	2.0	50.0
	Outdoors	2,024	7.3	4.9	7.0	2.0	11.0	1,992	4.8	4.2	3.0	1.0	7.0

Notes: Measurements in this table are expressed in ppb (rather than ppm).
N obs – Number of valid observations.
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

Measurements of TVOC and HCHO concentrations taken during the autumn and winter rounds of measurements were discarded due to sensor calibration issues.

* In School R exposure measurements were conducted in one classroom only, as the school had one composite class combining primary years 3 and 4. The second monitoring station was placed in a corridor connecting several classrooms.
‡ Measurements in Canteen in School S2 were conducted in the winter round only.

Table 15 Descriptive statistics – CO_2 (measured exposure), ppm

Season	Location	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	Classroom A	2,007	1,449	693	1,401	873	1,926	1,859	1,825	845	1,747	1,157	2,459
	Classroom B / Corridor*	2,010	775	217	726	615	898	1,861	2,085	960	1,947	1,382	2,804
	Hall	2,008	919	313	845	684	1,118	1,693	1,267	594	1,266	695	1,769
	Outdoors	1,968	395	23	389	379	405	1,798	442	162	419	402	439
Winter	Classroom A	–	–	–	–	–	–	2,028	2,161	996	1,992	1,459	2,843
	Classroom B / Corridor*	–	–	–	–	–	–	1,943	2,425	1,178	2,309	1,436	3,316
	Hall	–	–	–	–	–	–	1,592	897	498	809	483	1,203
	Outdoors	–	–	–	–	–	–	1,789	407	23	398	391	414
Summer	Classroom A	2,018	1,581	731	1,495	1,043	2,075	1,940	1,141	925	804	539	1,349
	Classroom B / Corridor*	2,018	633	165	600	500	720	1,957	1,468	1,283	891	614	2,078
	Hall	2,017	770	260	723	538	985	1,949	1,151	529	977	807	1,319
	Outdoors	2,001	395	17	389	384	399	1,941	433	31	429	408	445
Season	Location	School S2						School S3					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	Classroom A	2,005	993	262	999	809	1,159	1,858	3,414	940	3,343	2,960	4,018
	Classroom B	2,005	869	249	870	693	990	1,832	3,088	1,117	3,201	2,270	3,964
	Hall	2,005	725	186	696	585	817	1,633	955	380	848	647	1,227
	Outdoors	2,005	407	22	403	387	427	1,560	450	41	438	423	455
Winter	Classroom A	2,019	1,324	400	1,350	1,057	1,559	1,918	3,299	1,023	3,323	2,467	4,032
	Classroom B	2,019	1,488	600	1,354	1,088	1,716	1,580	3,754	1,181	3,687	3,009	4,393
	Hall	2,018	971	300	899	774	1,130	1,876	1,183	374	1,167	907	1,424
	Outdoors	2,019	417	31	426	406	438	1,776	418	30	412	392	434
	Canteen ‡	113	1,203	403	1,216	785	1,573	–	–	–	–	–	–
Summer	Classroom A	2,024	767	357	638	521	874	1,985	1,830	1,227	1,636	649	2,791
	Classroom B	2,021	792	241	745	594	975	2,008	1,852	1,175	1,553	859	2,802
	Hall	2,024	671	243	602	500	774	1,961	739	345	618	505	890
	Outdoors	2,024	412	22	405	393	434	1,931	421	23	429	396	438

Notes:

N obs – Number of valid observations.
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

* In School R exposure measurements were conducted in one classroom only, as the school had one composite class combining primary years 3 and 4. The second monitoring station was placed in a corridor connecting several classrooms.

No measurements were conducted in School R in the winter round due to logistic reasons.

‡ Measurements in Canteen in School S2 were conducted in the winter round only.

Table 16 Descriptive statistics – $PM_{0.5-5.0}$ (personal exposure), particles/L

Season	Class	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	1,987	5,493	2,745	4,549	3,408	7,317	2,017	7,353	5,565	6,885	4,688	8,373
	B	–	–	–	–	–	–	2,018	6,672	5,732	5,760	3,484	8,003
Winter	A	–	–	–	–	–	–	1,967	7,436	5,255	5,829	4,690	8,314
	B	–	–	–	–	–	–	1,965	6,993	5,419	5,087	4,218	7,696
Summer	A	2,017	4,858	1,700	4,917	3,503	5,924	1,970	9,466	7,728	6,290	4,297	12,492
	B	–	–	–	–	–	–	2,017	9,122	7,035	6,220	4,427	12,155
Season	**Class**	**School S2**						**School S3**					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	1,952	5,602	3,604	4,619	3,984	5,584	1,889	7,838	3,783	7,008	5,628	9,164
	B	2,010	5,593	3,376	4,759	4,112	5,826	2,007	8,819	3,945	7,719	6,434	10,407
Winter	A	2,025	19,981	17,496	16,904	6,468	27,790	1,691	7,839	4,234	7,014	4,336	9,517
	B	1,973	18,776	16,982	14,340	5,788	24,564	1,617	5,549	3,989	4,183	3,305	5,734
Summer	A	1,966	6,003	5,395	3,991	2,737	6,551	2,002	6,263	3,880	5,582	3,320	7,985
	B	2,024	5,660	4,736	4,149	2,879	6,629	2,003	5,878	3,260	5,611	3,748	7,188

Notes:

N obs – Number of valid observations.
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

* In School R exposure measurements were conducted in one classroom only and consequently personal exposure of one class only was modelled (A). No measurements were conducted in School R in the winter round due to logistic reasons.

Table 17 Descriptive statistics – CO (personal exposure), ppm

Season	Class	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	2,007	0.82	0.88	0.48	0.37	0.97	1,957	0.75	0.53	0.56	0.38	0.88
	B	–	–	–	–	–	–	1,955	0.85	0.59	0.61	0.36	1.31
Winter	A	–	–	–	–	–	–	1,909	0.68	0.43	0.59	0.41	0.82
	B	–	–	–	–	–	–	1,875	0.67	0.44	0.59	0.30	0.93
Summer	A	2,018	0.45	0.17	0.43	0.31	0.55	1,890	0.69	0.44	0.56	0.41	0.83
	B	–	–	–	–	–	–	1,950	0.67	0.51	0.50	0.29	0.87
Season	**Class**	**School S2**						**School S3**					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	1,945	0.46	0.09	0.45	0.39	0.53	1,625	0.64	0.26	0.64	0.43	0.83
	B	2,005	0.35	0.15	0.35	0.22	0.46	1,723	0.60	0.24	0.59	0.42	0.79
Winter	A	2,019	0.60	0.17	0.57	0.48	0.71	1,872	0.78	0.30	0.73	0.55	1.05
	B	1,974	0.59	0.27	0.54	0.38	0.77	1,367	0.81	0.34	0.84	0.50	1.06
Summer	A	1,978	0.48	0.18	0.46	0.40	0.56	1,970	0.54	0.19	0.52	0.43	0.64
	B	2,023	0.37	0.22	0.31	0.23	0.50	1,979	0.43	0.17	0.45	0.29	0.56

Notes:

N obs – Number of valid observations
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

* In School R exposure measurements were conducted in one classroom only and consequently personal exposure of one class only was modelled (A). No measurements were conducted in School R in the winter round due to logistic reasons.

Table 18 Descriptive statistics – NO_2 (personal exposure), ppb

Season	Class	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	2,007	51.6	5.6	51.0	48.0	55.0	1,957	55.3	8.3	55.0	50.0	60.0
	B	–	–	–	–	–	–	1,955	49.8	10.5	46.0	43.0	58.0
Winter	A	–	–	–	–	–	–	1,909	52.2	8.2	52.0	48.0	57.0
	B	–	–	–	–	–	–	1,875	47.6	9.0	45.0	42.0	50.0
Summer	A	2,018	51.7	9.0	50.0	45.0	58.0	1,892	54.0	9.5	55.0	49.0	60.0
	B	–	–	–	–	–	–	1,952	49.7	9.3	48.0	43.0	56.0
Season	**Class**	**School S2**						**School S3**					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	1,945	57.9	7.0	56.0	53.0	63.0	1,625	51.0	10.9	49.0	45.0	55.0
	B	2,005	54.5	8.5	52.0	48.0	61.0	1,723	48.8	11.6	45.0	42.0	52.0
Winter	A	2,019	54.6	7.4	53.0	49.0	57.0	1,872	57.0	10.4	57.0	53.0	62.0
	B	1,974	50.2	9.4	47.0	44.0	53.0	1,367	48.6	14.3	45.2	39.0	56.0
Summer	A	1,978	55.8	9.5	54.0	49.0	63.0	1,970	54.8	11.6	54.0	47.0	63.0
	B	2,023	50.7	11.5	48.0	42.0	60.0	1,978	49.8	12.5	46.0	42.0	56.0

Notes: Measurements in this table are expressed in ppb (rather than ppm).
N obs – Number of valid observations
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

* In School R exposure measurements were conducted in one classroom only and consequently personal exposure of one class only was modelled (A).
No measurements were conducted in School R in the winter round due to logistic reasons.

Table 19 Descriptive statistics – TVOC (personal exposure), ppm

Season	Class	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	A	2,018	0.25	0.23	0.18	0.14	0.25	1,892	0.21	0.29	0.09	0.05	0.22
	B	–	–	–	–	–	–	1,952	0.20	0.21	0.14	0.09	0.22
Season	Class	School S2						School S3					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	A	1,978	0.27	0.26	0.20	0.13	0.30	1,970	0.24	0.17	0.23	0.09	0.33
	B	2,023	0.36	0.23	0.33	0.26	0.38	1,979	0.30	0.19	0.29	0.13	0.46

Notes:

N obs – Number of valid observations
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

Measurements of TVOC and HCHO concentrations taken during the autumn and winter rounds of measurements were discarded due to sensor calibration issues.

* In School R exposure measurements were conducted in one classroom only and consequently personal exposure of one class only was modelled (A).

Table 20 Descriptive statistics – HCHO (personal exposure), ppb

Season	Class	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	A	2,018	26.7	26.5	25.0	6.0	32.0	1,904	40.7	74.9	11.0	1.0	31.5
	B	–	–	–	–	–	–	1,960	40.7	63.9	11.0	2.0	41.0
Season	Class	School S2						School S3					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Summer	A	1,978	15.9	13.7	13.0	2.0	27.0	2,002	24.1	23.9	15.0	1.0	40.0
	B	2,024	16.5	12.4	14.0	5.0	28.0	2,004	20.2	21.1	8.0	1.0	40.0

Notes: Measurements in this table are expressed in ppb (rather than ppm).
See notes to Table 19.

Table 21 Descriptive statistics – CO_2 (personal exposure), ppm

Season	Class	School R*						School S1					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	2,007	1,261	724	1,189	608	1,767	1,957	1,534	955	1,522	607	2,101
	B	–	–	–	–	–	–	1,955	1,741	1,121	1,644	620	2,586
Winter	A	–	–	–	–	–	–	1,909	2,050	1,183	1,961	1,207	2,885
	B	–	–	–	–	–	–	1,875	2,269	1,387	2,264	1,137	3,458
Summer	A	2,015	1,302	802	1,238	428	1,837	1,892	1,332	1,177	863	493	1,619
	B	–	–	–	–	–	–	1,952	1,521	1,373	916	488	2,200
Season	**Class**	**School S2**						**School S3**					
		N obs	Mean	SD	Median	Q1	Q3	N obs	Mean	SD	Median	Q1	Q3
Autumn	A	1,945	985	362	1,028	772	1,197	1,625	2,695	1,510	2,975	1,327	3,793
	B	2,005	885	340	894	657	1,050	1,723	2,364	1,412	2,333	1,191	3,662
Winter	A	2,019	1,261	504	1,356	914	1,578	1,872	2,517	1,436	2,572	1,282	3,665
	B	1,974	1,412	679	1,388	1,033	1,745	1,367	2,834	1,792	2,974	1,187	4,232
Summer	A	1,978	809	419	649	509	920	1,970	1,525	1,159	1,088	464	2,425
	B	2,023	823	351	759	556	1,031	1,979	1,521	1,200	1,156	461	2,198

Notes:

N obs – Number of valid observations
Mean – Mean
SD – Standard deviation
Median – Median
Q1 – 25th percentile
Q3 – 75th percentile

* In School R exposure measurements were conducted in one classroom only and consequently personal exposure of one class only was modelled (A). No measurements were conducted in School R in the winter round due to logistic reasons.

Figure 2 $PM_{0.5-5.0}$ exposures (particles/L): measured indoors and personal, by school – autumn round of measurements.

Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B. Outdoor exposures are shown separately in Figure 5 due to differences in concentration ranges and consequently larger Y-scale of the box plots for outdoors exposures.

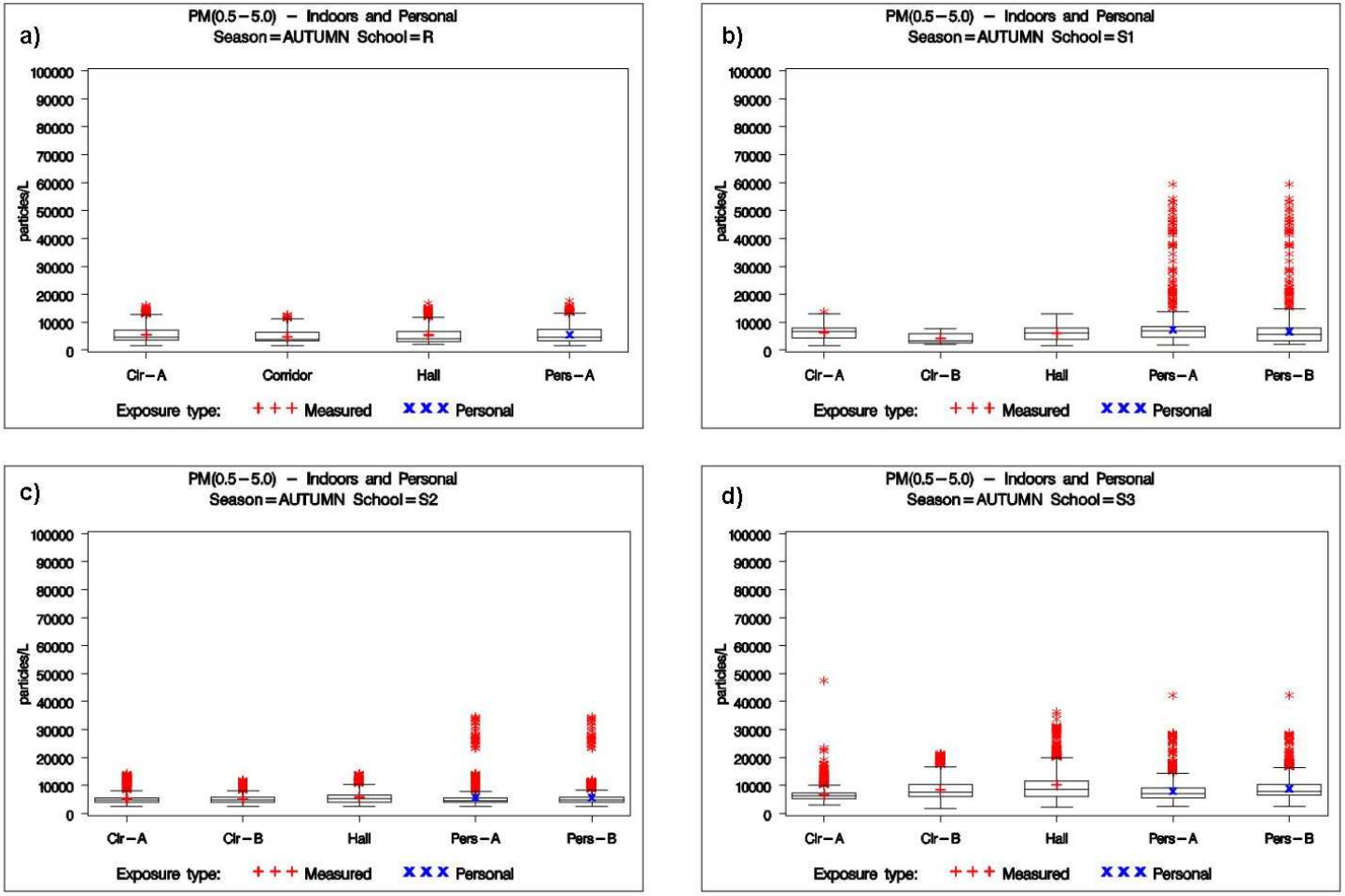
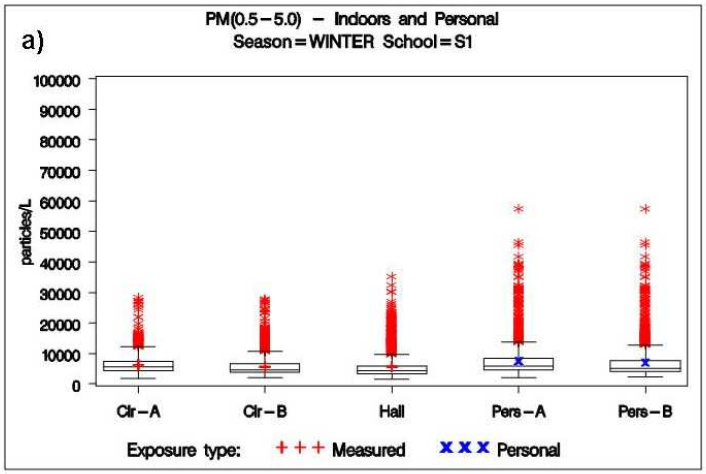
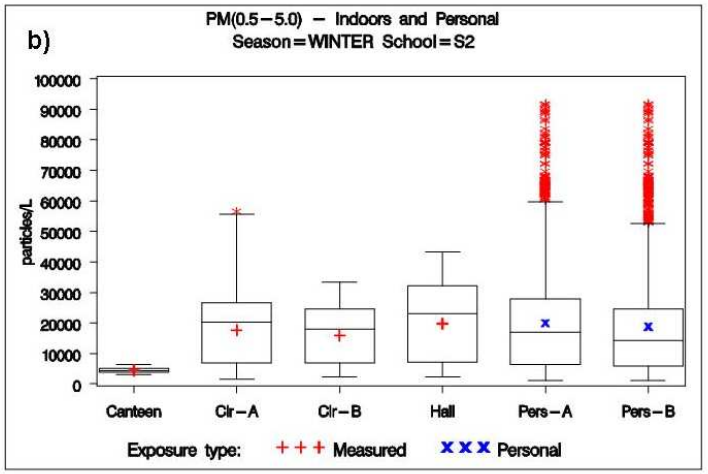


Figure 3 $PM_{0.5-5.0}$ exposures (particles/L): measured indoors and personal, by school – winter round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.





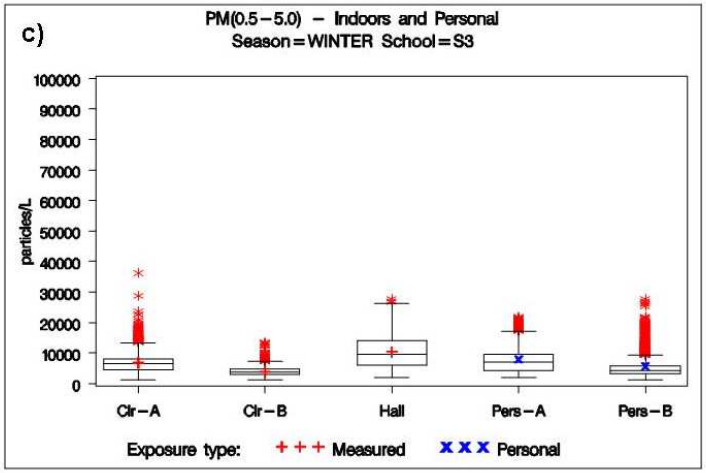


Figure 4 $PM_{0.5-5.0}$ exposures (particles/L): measured indoors and personal, by school – summer round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

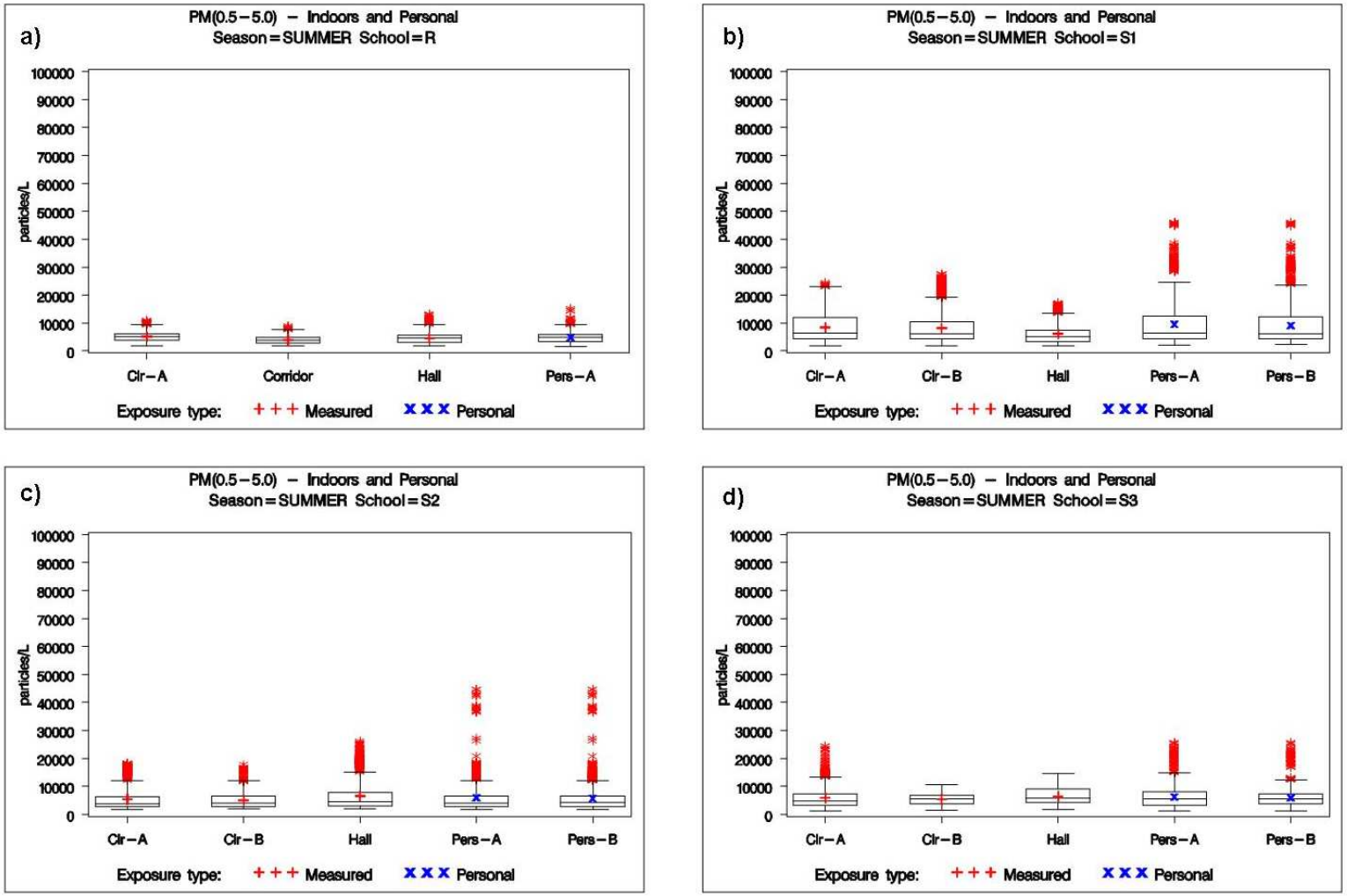


Figure 5 $PM_{0.5-5.0}$ exposures measured outdoors (particles/L), by season.

Note: For legend see Figure 17. Part D of the figure illustrates erroneously high outdoor winter measurements in school S3 (excluded from the analysis).

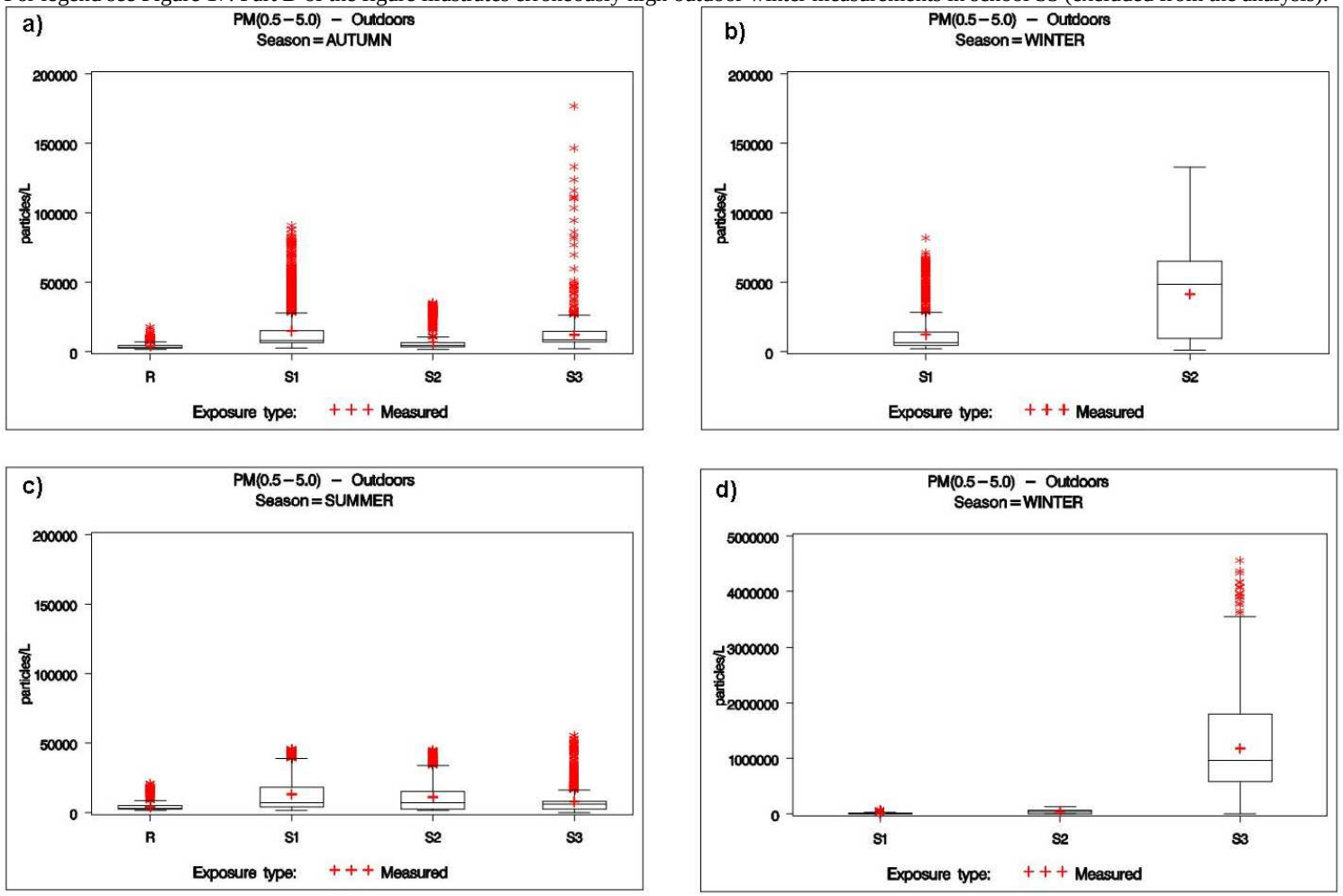


Figure 6 CO exposures (ppm), by school – autumn round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

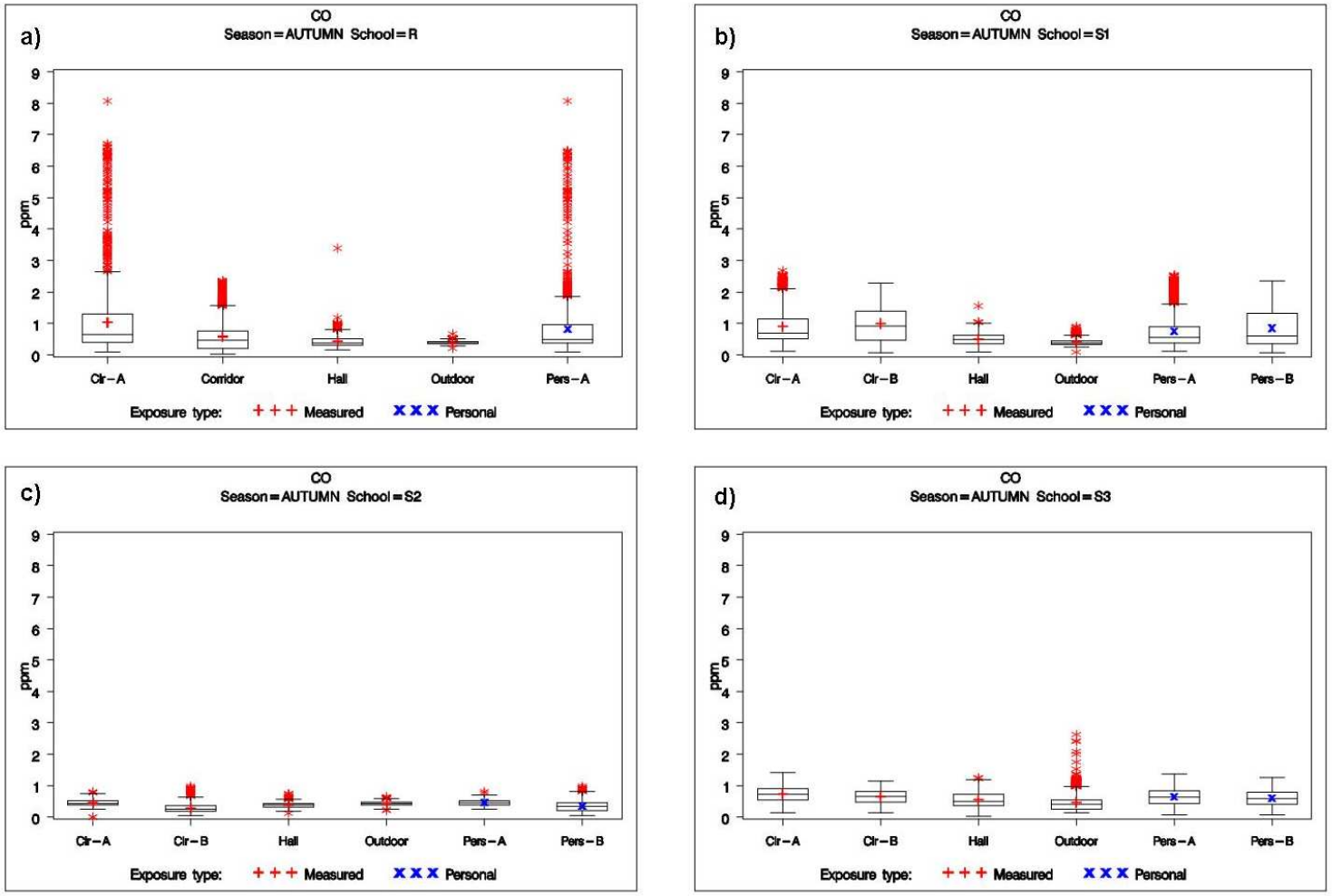
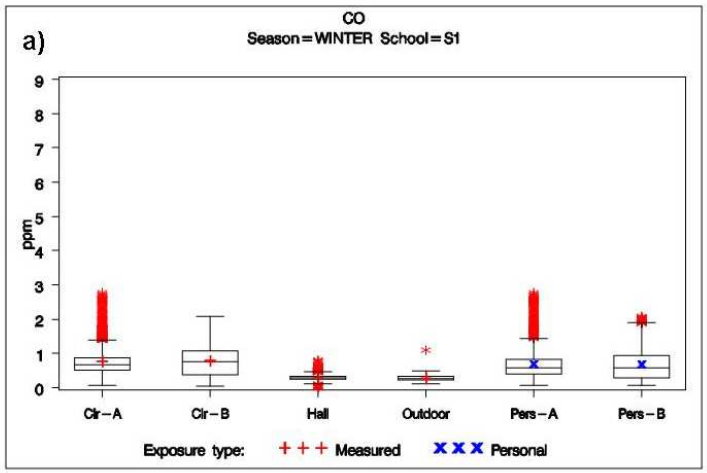
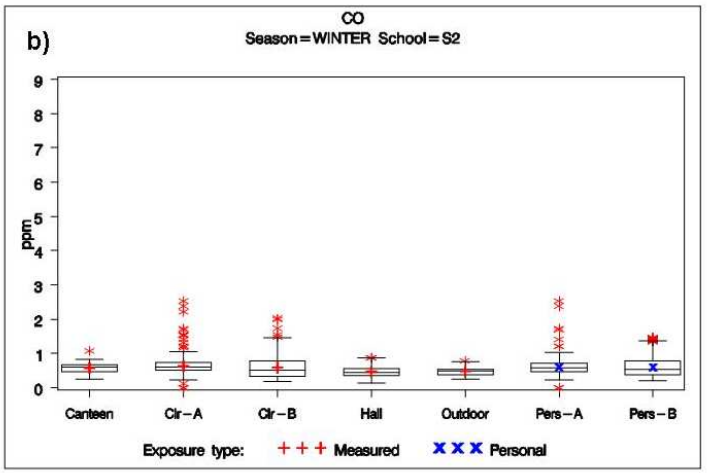


Figure 7 CO exposures (ppm), by school – winter round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.





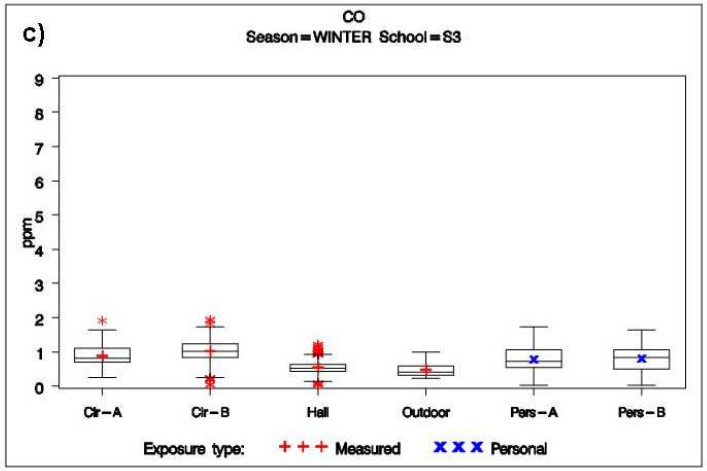


Figure 8 CO exposures (ppm), by school – summer round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

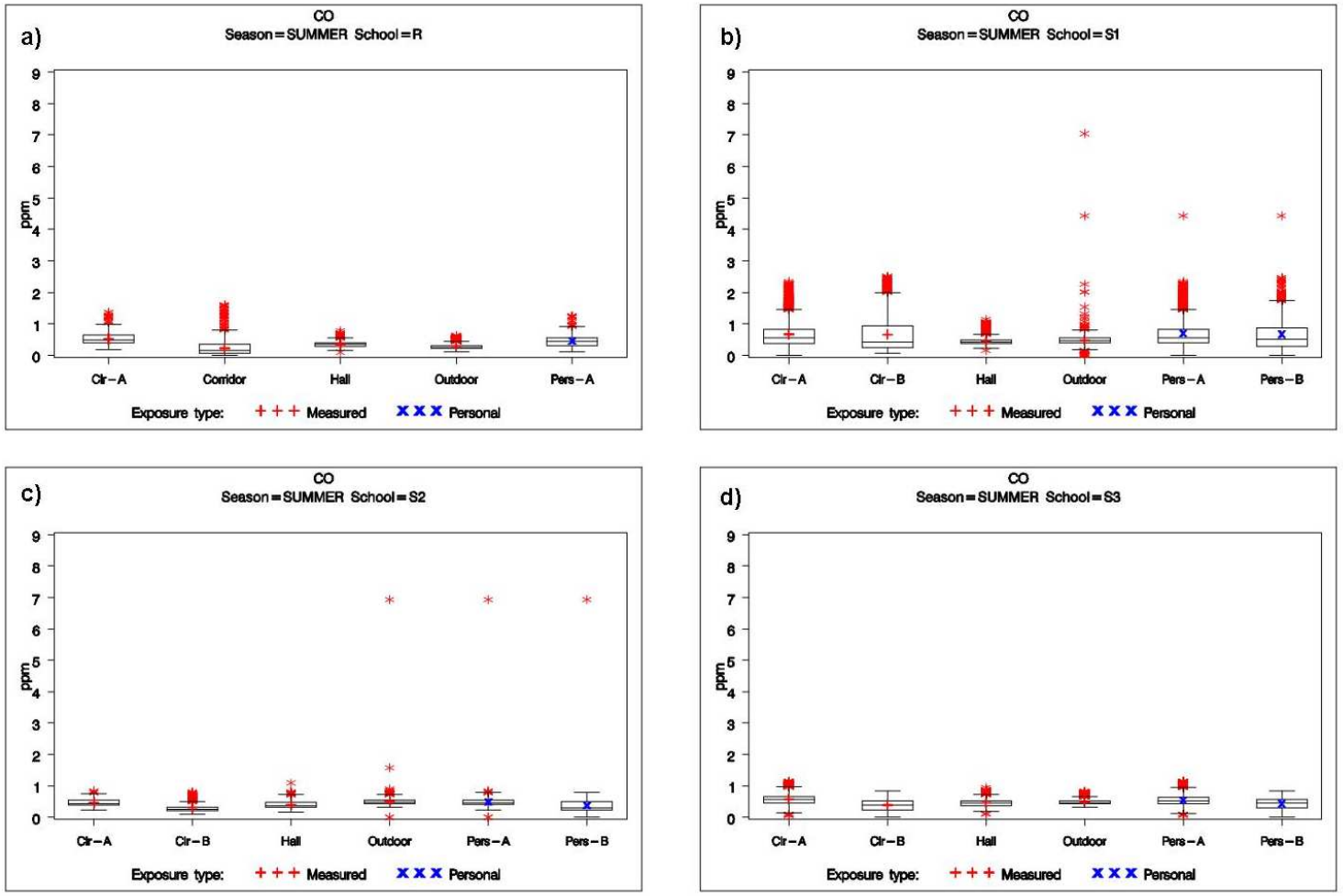


Figure 9 NO_2 exposures (ppm), by school – autumn round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

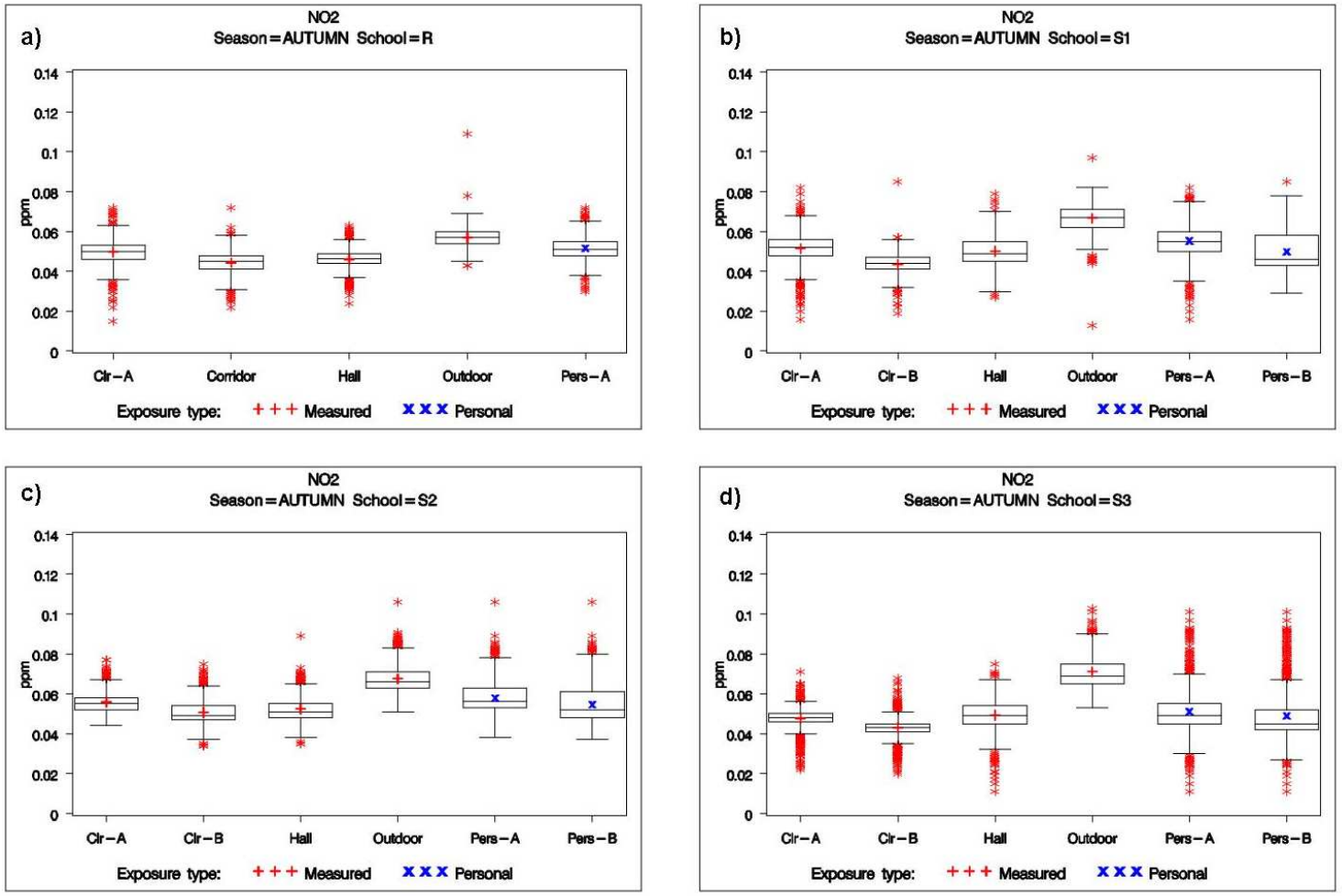
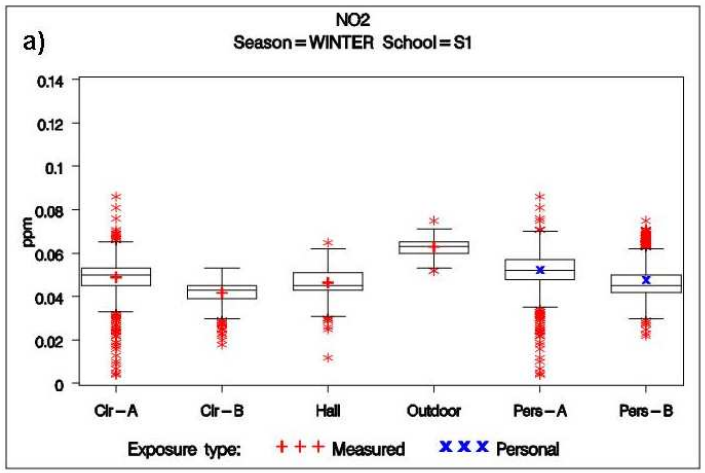
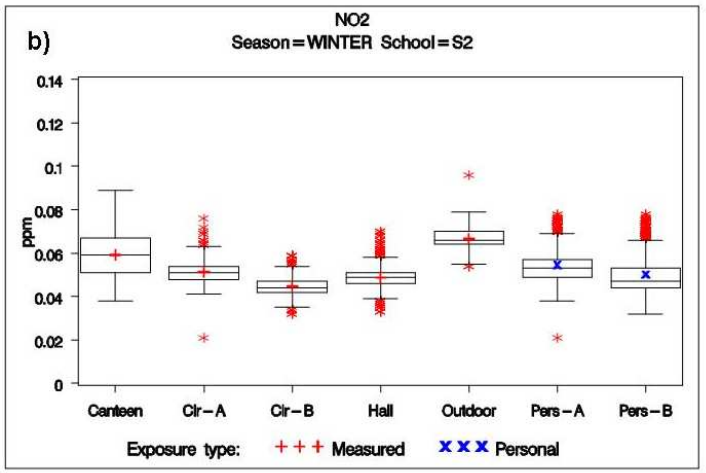


Figure 10 NO_2 exposures (ppm), by school – winter round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.





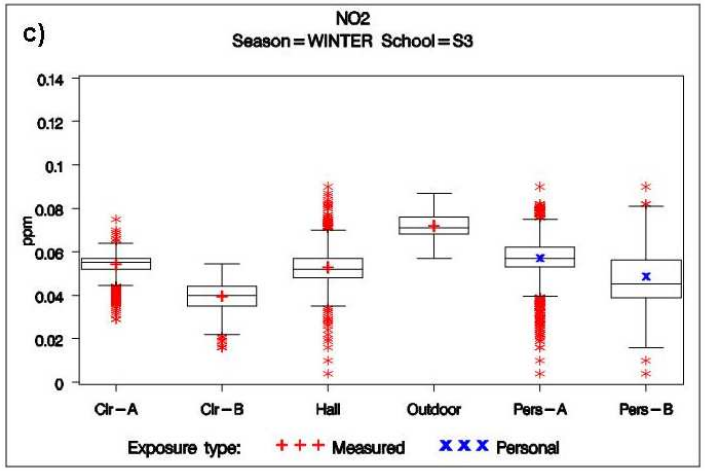


Figure 11 NO_2 exposures (ppm), by school – summer round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

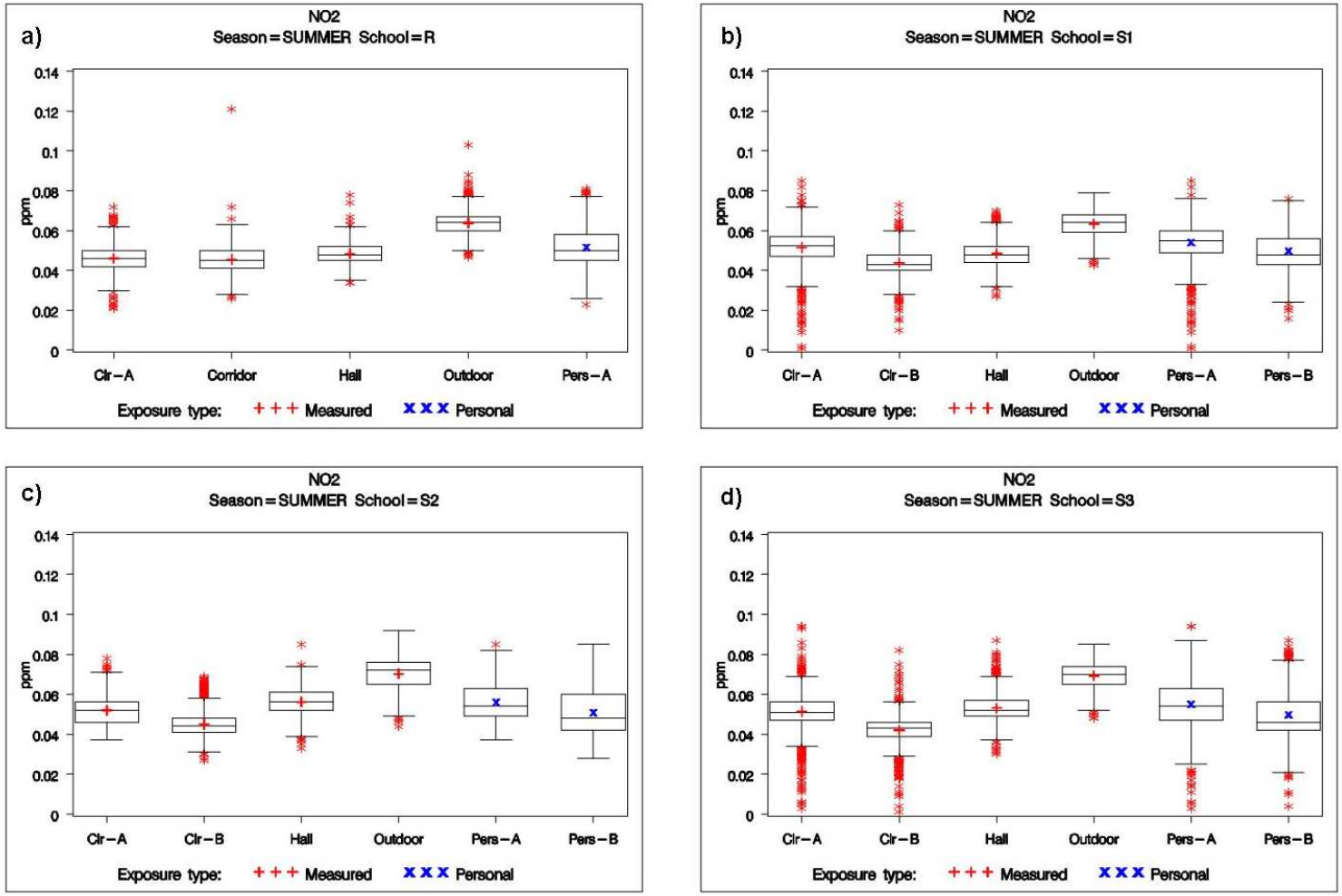


Figure 12 TVOC exposures (ppm), by school – summer round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

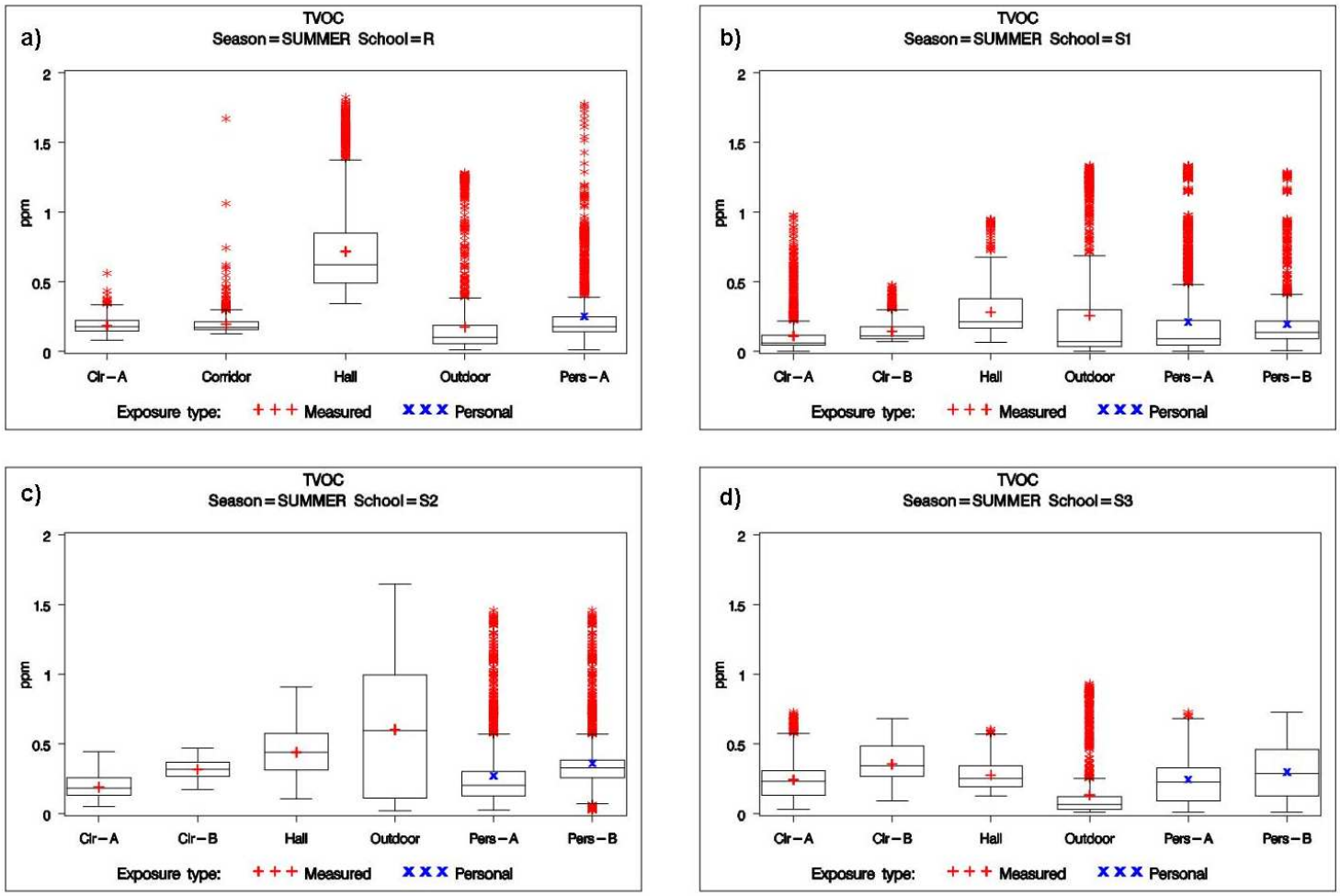


Figure 13 HCHO exposures (ppm), by school – summer round of measurements.
Note: For legend seeFigure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

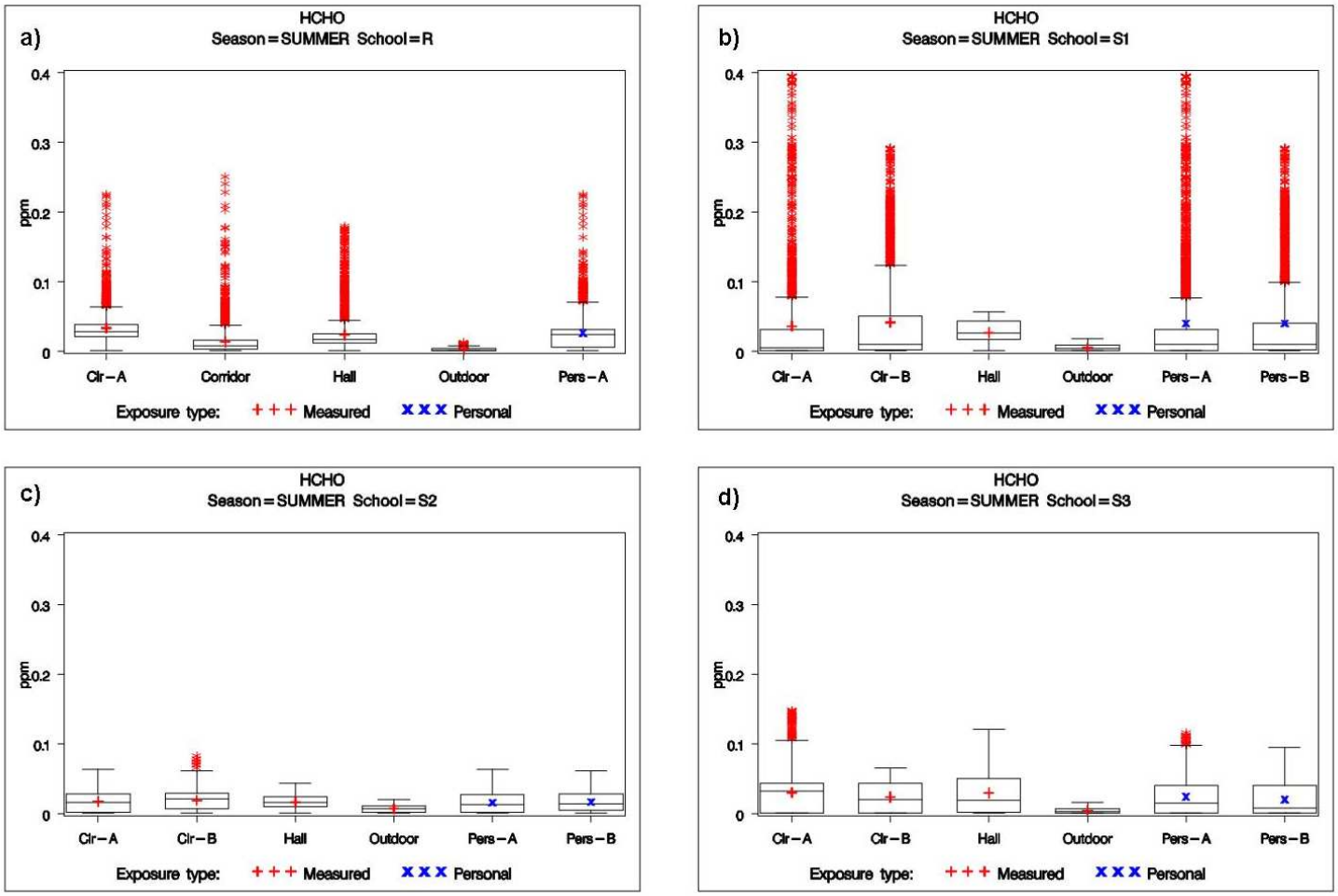


Figure 14 CO_2 exposures (ppm), by school – autumn round of measurements.

Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

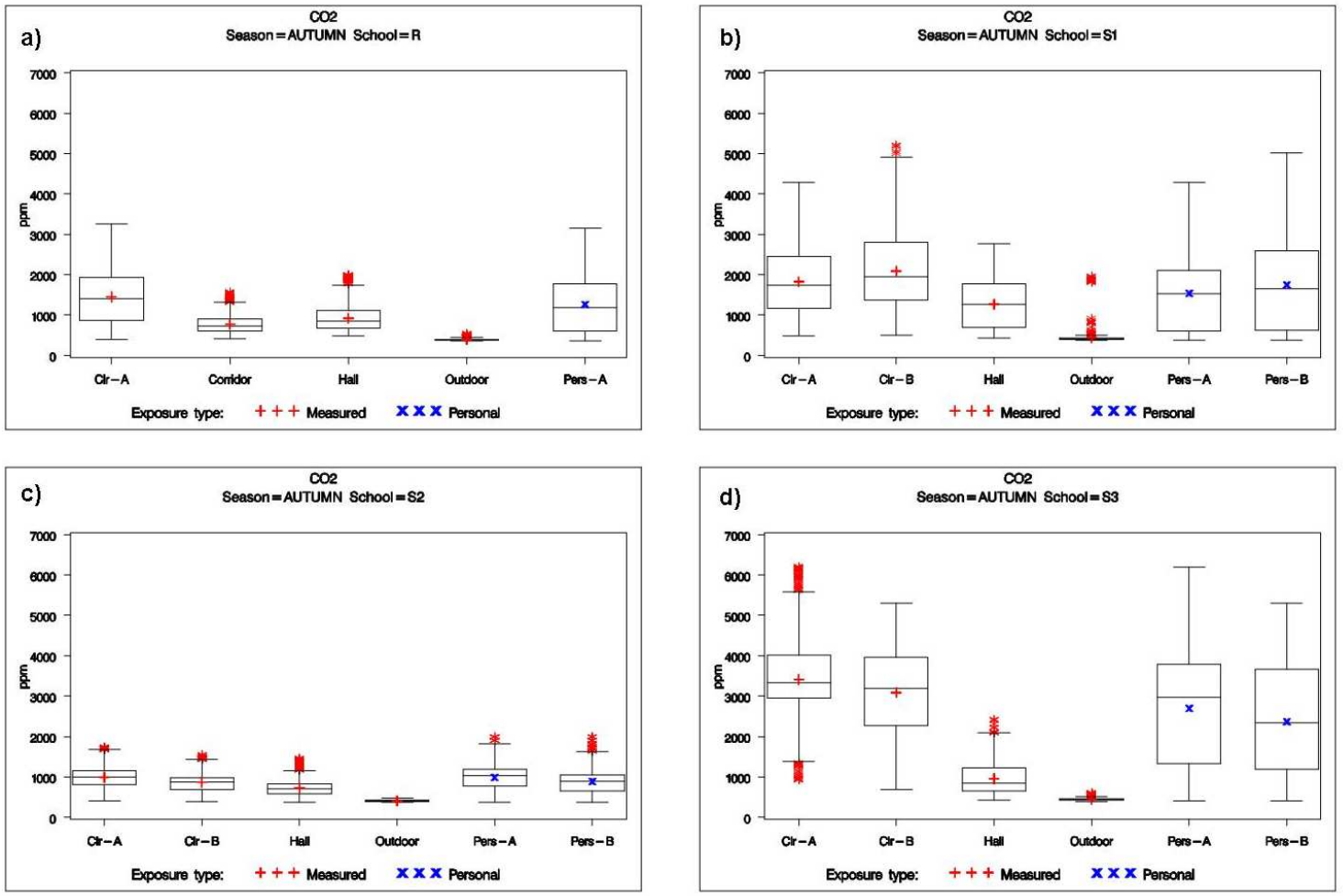
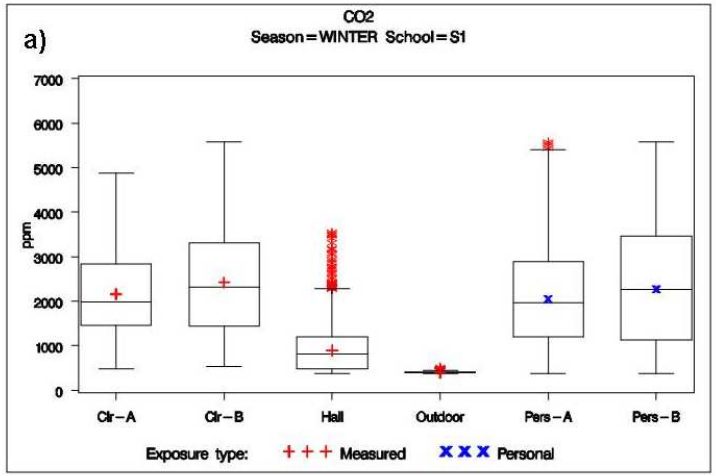
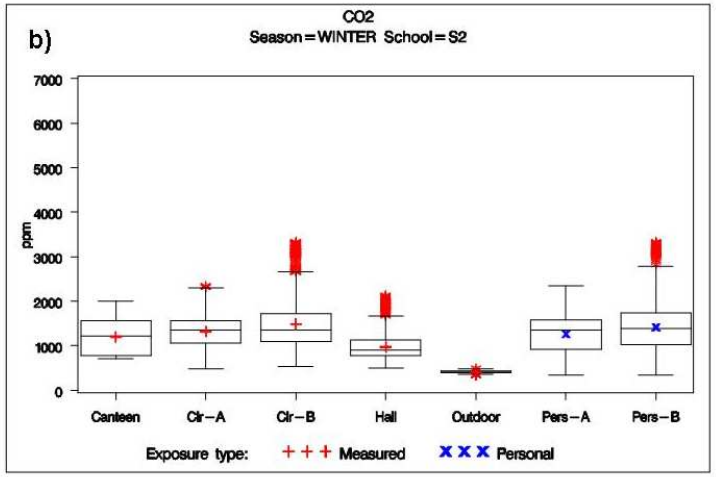


Figure 15 CO_2 exposures (ppm), by school – winter round of measurements.

Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.





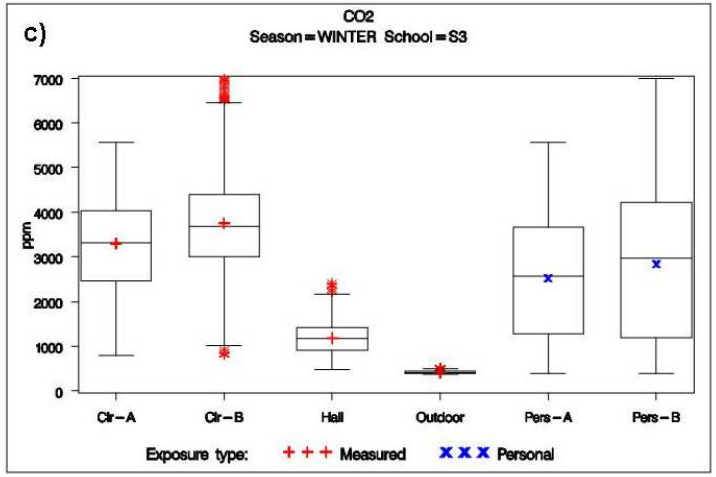


Figure 16 CO_2 exposures (ppm), by school – summer round of measurements.
Note: For legend see Figure 17. Clr-A and Clr-B are measured exposures in classrooms A and B; Pers-A and Pers-B are modelled personal exposures for classes A and B.

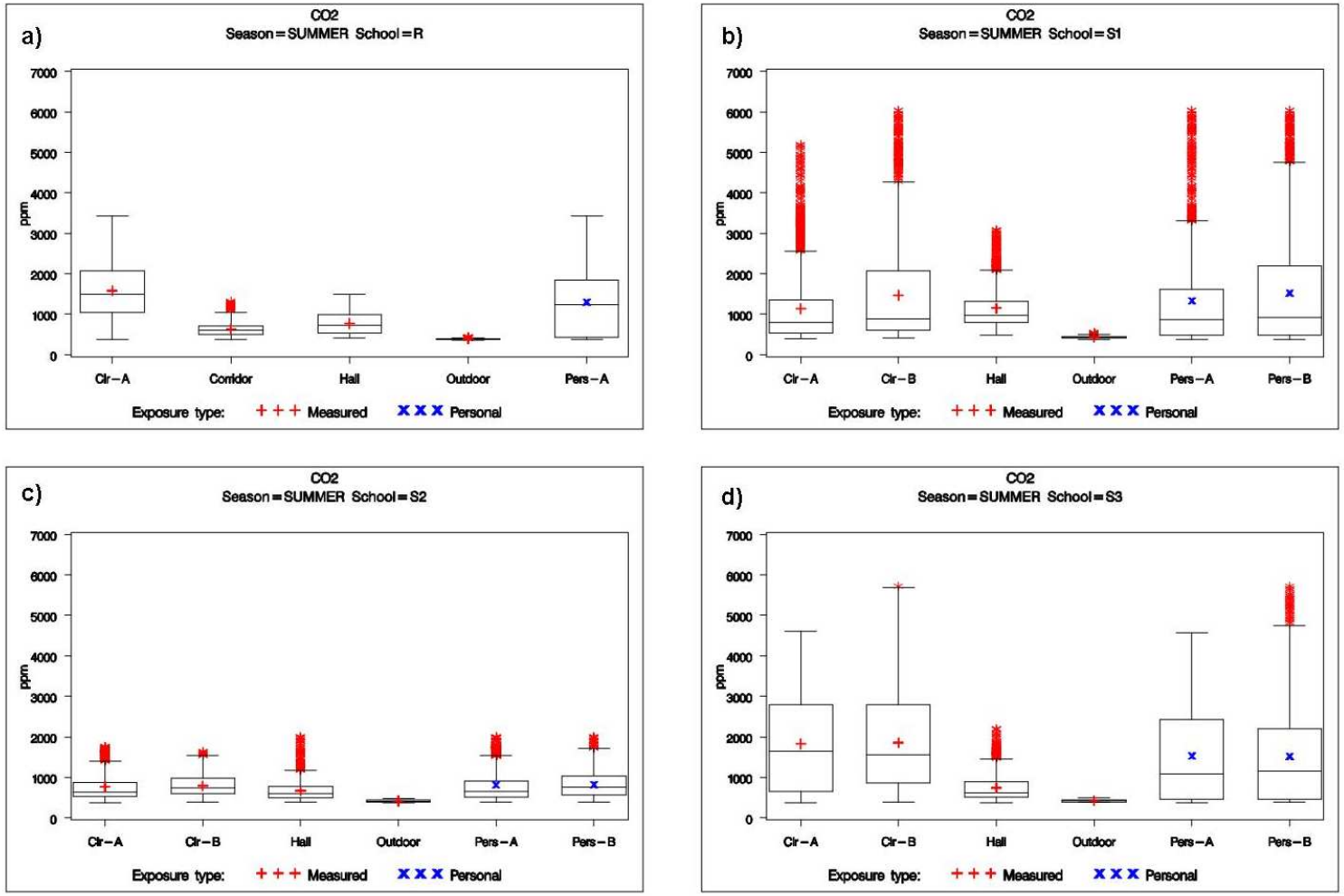
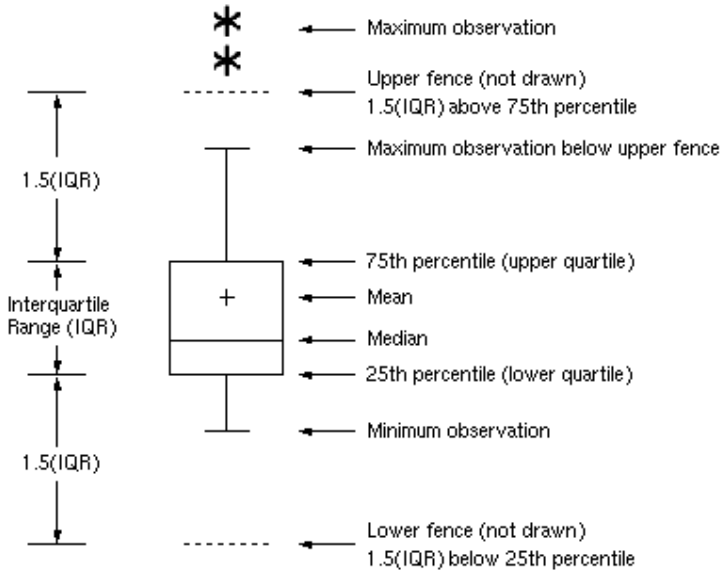


Figure 17 Box Plots legend



Schools:
R – Rural school;
S1, S2, S3 – Suburban schools.

Measured exposure:
Clr-A – measured exposures in classrooms A
(in School R the measurements were conducted only in one classroom, as due to small size of classes all Primary 3 and 4 children were located in one classroom);
Clr-B – measured exposures in classrooms B;
Hall – exposures measured in assembly / physical education hall;
Outdoor – exposure measured outdoors;
Corridor – exposure measured in a corridor connecting several classes with hall (in School R only);
Canteen – exposures measured in a canteen (in School S2 in the winter round of measurements only).

Personal exposure:
Pers-A – modelled personal exposures of class A;
Pers-B – modelled personal exposures of class B.

Rounds of measurements:
Three rounds of measurements were conducted altogether – in autumn, winter and summer, however School S was included in two rounds of measurements only (autumn and summer), due to logistic reasons.

Measurements of TVOC and HCHO concentrations taken during the autumn and winter rounds of measurements were discarded due to sensor calibration issues.

Figure 18 Results of independent group T-test: Difference between means of Personal and Measured exposures (Class A and Classroom A), $PM_{0.5-50}$ (particles/L)

Mean – mean difference (PE-ME)
Lower CL (Mean) – lower confidence limit of the mean
Upper CL (Mean) – upper confidence limit of the mean
P-value - two-tailed probability. P-values were calculated using Satterthwaite's method, as the two groups' (PE and ME) variances proved to be unequal. P-values in bold exceed α = 0.05.

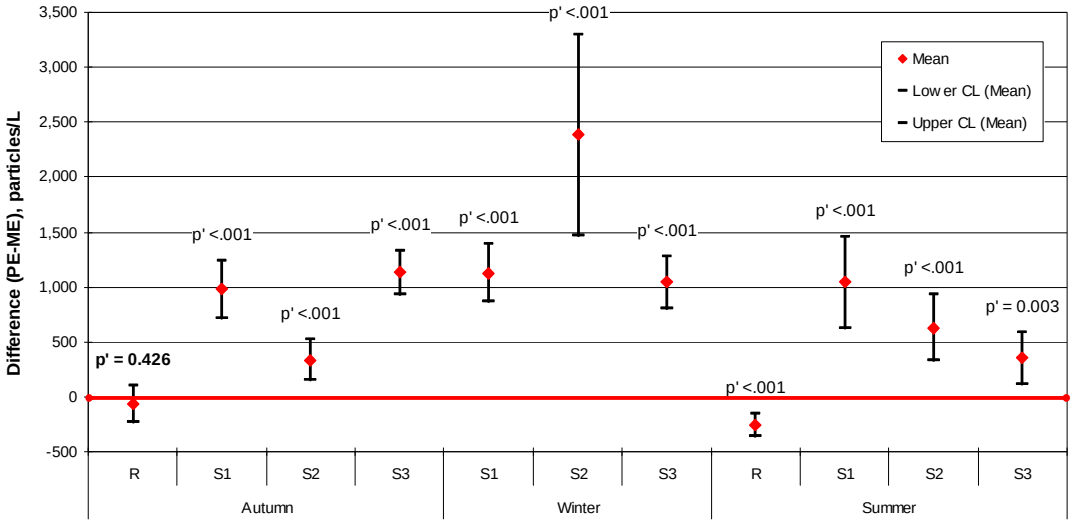


Figure 19 Results of independent group T-test: Difference between means of Personal and Measured exposures (Class A and Classroom A), CO (ppm)

Mean – mean difference (PE-ME)
Lower CL (Mean) – lower confidence limit of the mean
Upper CL (Mean) – upper confidence limit of the mean
P-value - two-tailed probability. P-values were calculated using Satterthwaite's method, as the two groups' (PE and ME) variances proved to be unequal. P-values in bold exceed α = 0.05.

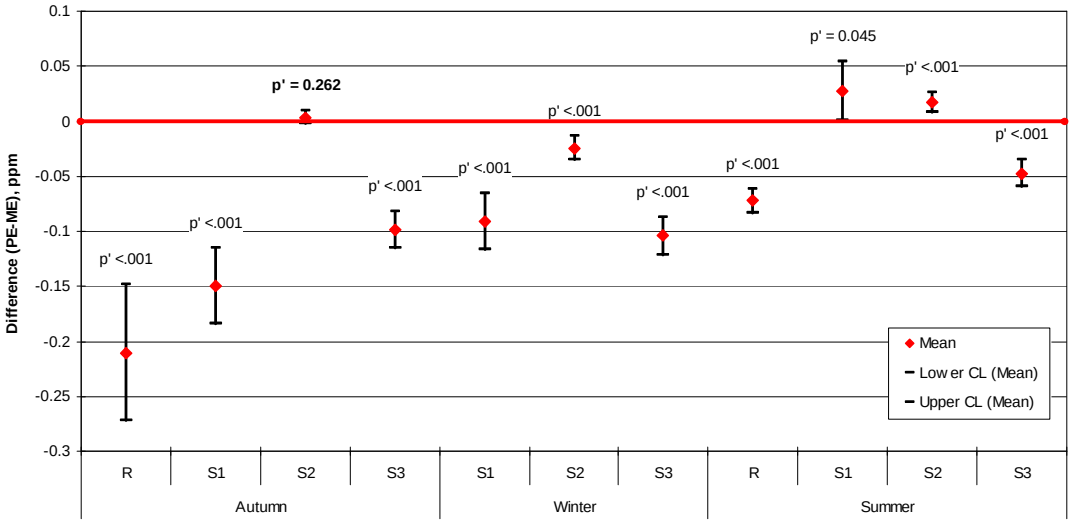


Figure 20 Results of independent group T-test: Difference between means of Personal and Measured exposures (Class A and Classroom A), NO_2 (ppb)

Mean – mean difference (PE-ME)
Lower CL (Mean) – lower confidence limit of the mean
Upper CL (Mean) – upper confidence limit of the mean
P-value - two-tailed probability. P-values were calculated using Satterthwaite's method, as the two groups' (PE and ME) variances proved to be unequal. P-values in bold exceed α = 0.05.

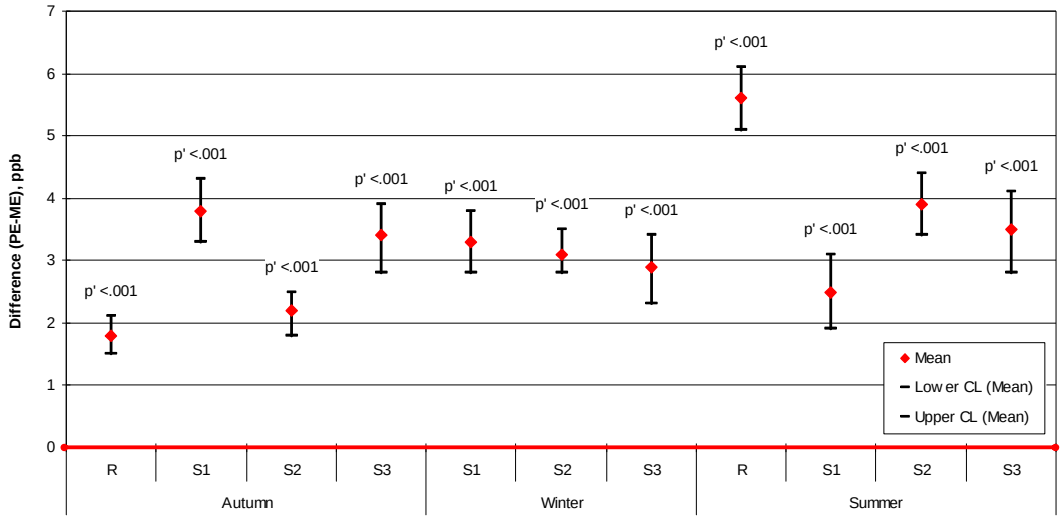


Figure 21 Results of independent group T-test: Difference between means of Personal and Measured exposures(Class A and Classroom A), TVOC (ppm)

Mean – mean difference (PE-ME)
Lower CL (Mean) – lower confidence limit of the mean
Upper CL (Mean) – upper confidence limit of the mean
P-value - two-tailed probability. P-values were calculated using Satterthwaite's method, as the two groups' (PE and ME) variances proved to be unequal. P-values in bold exceed α = 0.05.

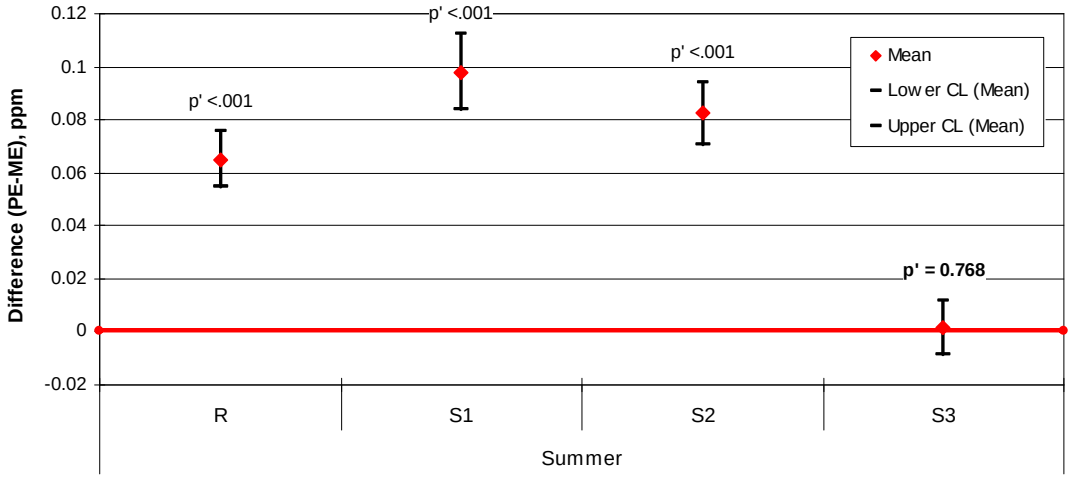


Figure 22 Results of independent group T-test: Difference between means of Personal and Measured exposures (Class A and Classroom A), HCHO (ppb)

Mean – mean difference (PE-ME)
Lower CL (Mean) – lower confidence limit of the mean
Upper CL (Mean) – upper confidence limit of the mean
P-value - two-tailed probability. P-values were calculated using Satterthwaite's method, as the two groups' (PE and ME) variances proved to be unequal. P-values in bold exceed α = 0.05.

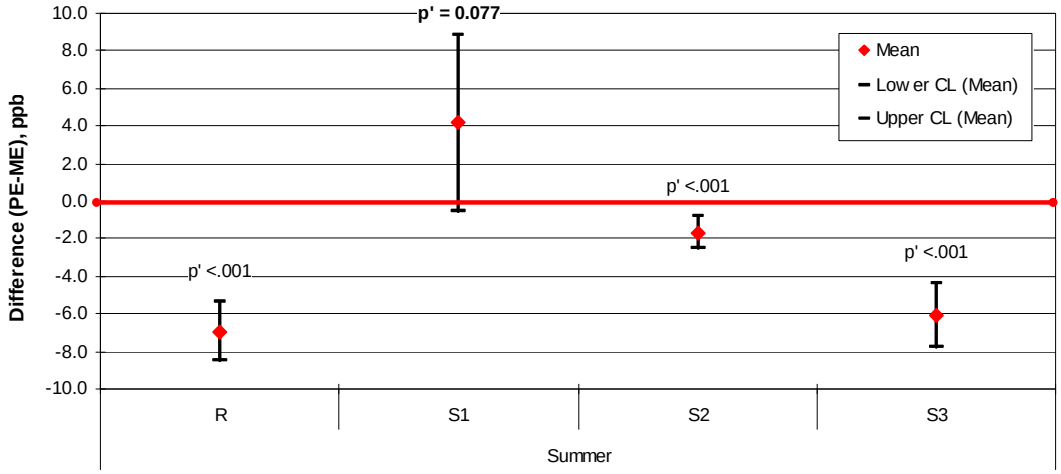


Figure 23 Results of independent group T-test: Difference between means of Personal and Measured exposures (Class A and Classroom A), CO_2 (ppm)

Mean – mean difference (PE-ME)
Lower CL (Mean) – lower confidence limit of the mean
Upper CL (Mean) – upper confidence limit of the mean
P-value - two-tailed probability. P-values were calculated using Satterthwaite's method, as the two groups' (PE and ME) variances proved to be unequal. P-values in bold exceed α = 0.05.

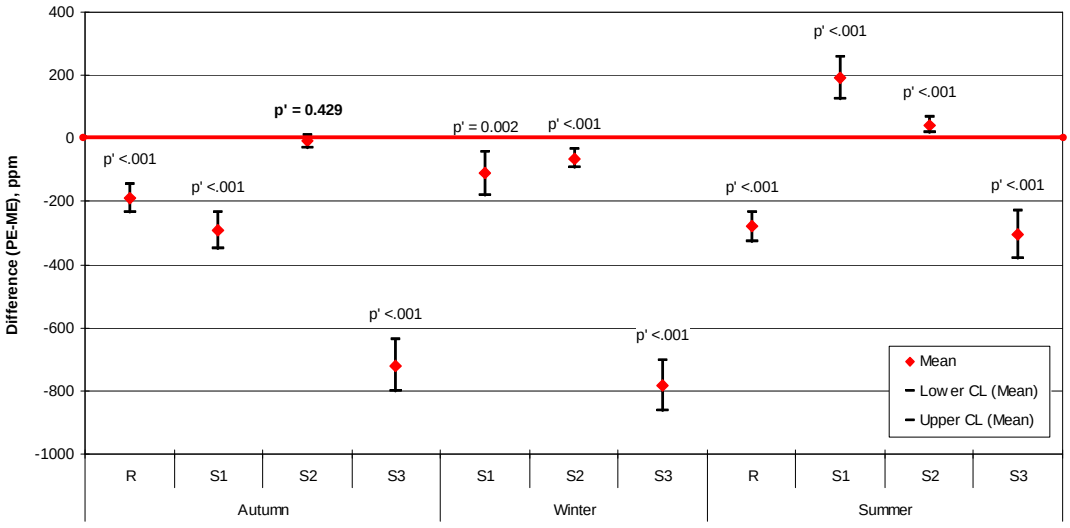


Table 22 Results of independent group T-test: Difference between means of Personal and Measured exposures (Class A and Classroom A), by pollutant.

Mean – mean difference (PE-ME)
Lower CL (Mean) – lower confidence limit of the mean
Upper CL (Mean) – upper confidence limit of the mean
P-value - two-tailed probability. P-values were calculated using Satterthwaite's method, as the two groups' (PE and ME) variances proved to be unequal. P-values in bold exceed $\alpha = 0.05$.

a)

		Difference between means (PE-ME), particles/L			
PM(0.5-5.0)	**School**	**Mean**	**Lower CL (Mean)**	**Upper CL (Mean)**	**P-value**
Autumn	**R**	-67	-233	98	**0.426**
	S1	981	717	1,244	<.001
	S2	337	151	522	<.001
	S3	1,131	934	1,328	<.001
Winter	**S1**	1,127	864	1,391	<.001
	S2	2,383	1,471	3,295	<.001
	S3	1,045	808	1,282	<.001
Summer	**R**	-253	-356	-150	<.001
	S1	1,044	630	1,457	<.001
	S2	631	334	927	<.001
	S3	353	119	586	0.003

b)

		Difference between means (PE-ME), ppm			
CO	**School**	**Mean**	**Lower CL (Mean)**	**Upper CL (Mean)**	**P-value**
Autumn	**R**	-0.211	-0.272	-0.149	<.001
	S1	-0.149	-0.184	-0.115	<.001
	S2	0.003	-0.002	0.009	**0.262**
	S3	-0.099	-0.116	-0.082	<.001
Winter	**S1**	-0.091	-0.117	-0.065	<.001
	S2	-0.025	-0.036	-0.014	<.001
	S3	-0.104	-0.122	-0.087	<.001
Summer	**R**	-0.072	-0.083	-0.061	<.001
	S1	0.028	0.001	0.054	0.045
	S2	0.017	0.008	0.026	<.001
	S3	-0.047	-0.059	-0.035	<.001

c)

		Difference between means (PE-ME), ppb			
NO2	**School**	**Mean**	**Lower CL (Mean)**	**Upper CL (Mean)**	**P-value**
Autumn	**R**	1.8	1.5	2.1	<.001
	S1	3.8	3.3	4.3	<.001
	S2	2.2	1.8	2.5	<.001
	S3	3.4	2.8	3.9	<.001
Winter	**S1**	3.3	2.8	3.8	<.001
	S2	3.1	2.8	3.5	<.001
	S3	2.9	2.3	3.4	<.001
Summer	**R**	5.6	5.1	6.1	<.001
	S1	2.5	1.9	3.1	<.001
	S2	3.9	3.4	4.4	<.001
	S3	3.5	2.8	4.1	<.001

d)

		Difference between means (PE-ME), ppm			
CO2	**School**	**Mean**	**Lower CL (Mean)**	**Upper CL (Mean)**	**P-value**
Autumn	**R**	-189	-232	-145	<.001
	S1	-290	-348	-233	<.001
	S2	-8	-28	12	**0.429**
	S3	-719	-801	-636	<.001
Winter	**S1**	-110	-179	-42	0.002
	S2	-64	-92	-35	<.001
	S3	-782	-861	-703	<.001
Summer	**R**	-279	-326	-232	<.001
	S1	192	125	259	<.001
	S2	42	18	66	<.001
	S3	-304	-379	-230	<.001

e)

		Difference between means (PE-ME), ppm			
TVOC	**School**	**Mean**	**Lower CL (Mean)**	**Upper CL (Mean)**	**P-value**
Summer	**R**	0.065	0.055	0.075	<.001
	S1	0.098	0.084	0.112	<.001
	S2	0.083	0.071	0.094	<.001
	S3	0.002	-0.009	0.012	**0.768**

f)

		Difference between means (PE-ME), ppb			
HCHO	**School**	**Mean**	**Lower CL (Mean)**	**Upper CL (Mean)**	**P-value**
Summer	**R**	-7.0	-8.5	-5.4	<.001
	S1	4.2	-0.5	8.8	**0.077**
	S2	-1.7	-2.5	-0.8	<.001
	S3	-6.1	-7.8	-4.4	<.001

Table 23 Results of linear regression: model PE = ME

Season	School	Coefficient of determination (R^2)					
		PM(0.5-5.0)	CO	NO_2	HCHO	TVOC	CO_2
Autumn	R	**0.82**	**0.54**	0.38	–	–	**0.55**
	S1	0.22	0.49	0.27	–	–	0.49
	S2	**0.65**	**0.75**	0.30	–	–	0.43
	S3	0.16	**0.62**	0.11	–	–	0.24
Winter	S1	0.32	**0.70**	0.26	–	–	**0.56**
	S2	0.49	**0.61**	0.15	–	–	0.39
	S3	0.31	0.45	0.09	–	–	0.18
Summer	R	0.38	0.42	0.10	0.44	0.001*	0.47
	S1	**0.60**	**0.54**	0.39	**0.85**	0.19	0.32
	S2	**0.73**	0.21	0.33	**0.75**	0.18	0.41
	S3	0.46	0.47	0.15	0.47	**0.51**	0.40

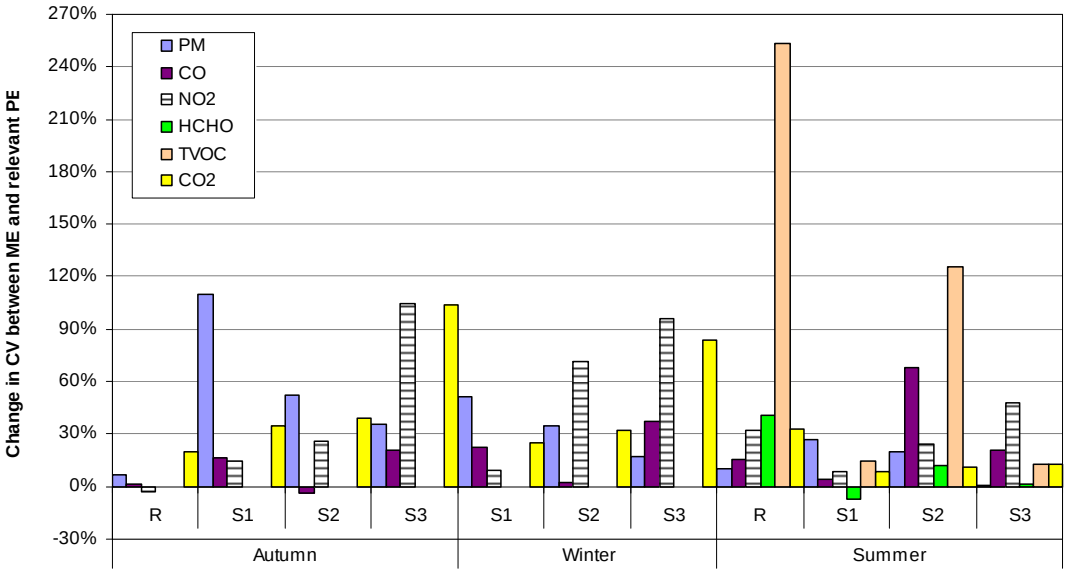
Note: R^2 in bold exceed 0.5 (i.e. 50% of more of PE is explained by ME)
All results were statistically significant with p' < 0.0001, except for * p = 0.29.

Table 24 Percent change in coefficients of variation (CV %) between ME in Classroom A and PE for Class A

Season	School	Pollutant					
		$PM_{0.5-5.0}$	CO	NO_2	HCHO	TVOC	CO_2
Autumn	**R**	7%	1%	-3%	–	–	20%
	S1	**110%**	16%	15%	–	–	**34%**
	S2	**52%**	-4%	**26%**	–	–	**39%**
	S3	**36%**	20%	**104%**	–	–	**104%**
Winter	**S1**	**51%**	**22%**	9%	–	–	**25%**
	S2	**34%**	2%	**71%**	–	–	**32%**
	S3	18%	**37%**	**96%**	–	–	**84%**
Summer	**R**	10%	16%	**32%**	**41%**	**253%**	**33%**
	S1	**27%**	5%	9%	-7%	15%	9%
	S2	20%	**68%**	**25%**	12%	**126%**	11%
	S3	1%	20%	**47%**	2%	13%	13%

Notes: Table 24 presents percentage of change in coefficients of variation (CV) between measured exposure in Classroom A and modelled personal exposure of Class A, where ME in Class A is 100%.
Percentages in bold exceed 20%.

Figure 24 Percent change in coefficients of variation (CV %) between ME in Classroom A and PE for Class A



Notes: Figure 24 presents percentage of change in coefficients of variation (CV) between measured exposures in Classroom A and modelled personal exposures of Class A.

Table 25 Number and percentage of returned questionnaires with one, two and three or more answers missing.

School	Total number of chilfren with returtned questionnaires	Health part - questionnaires with:						Home environment part - questionnaires with:						Socioeconomic status part - questionnaires with:					
		1 missing answer		2 missing answers		3+ missing answers		1 missing answer		2 missing answers		3+ missing answers		1 missing answer		2 missing answers		3+ missing answers	
		Number	% of returned	Number	% of returned	Number	% of returned	Number	% of returned	Number	% of returned	Number	% of returned	Number	% of returned	Number	% of returned	Number	% of returned
R	58	5	8.6%	0	0.0%	1	1.7%	8	13.8%	0	0.0%	1	1.7%	3	5.2%	8	13.8%	2	3.4%
S1	54	4	7.4%	0	0.0%	2	3.7%	3	5.6%	1	1.9%	0	0.0%	6	11.1%	6	11.1%	3	5.6%
S2	44	3	6.8%	1	2.3%	5	11.4%	14	31.8%	6	13.6%	5	11.4%	6	13.6%	4	9.1%	18	40.9%
S3	11	0	0.0%	0	0.0%	1	9.1%	1	9.1%	0	0.0%	1	9.1%	3	27.3%	0	0.0%	1	9.1%
All schools	**167**	**12**	**7.2%**	**1**	**0.6%**	**9**	**5.4%**	**26**	**15.6%**	**7**	**4.2%**	**7**	**4.2%**	**18**	**10.8%**	**18**	**10.8%**	**24**	**14.4%**

Figure 25 Propitiations of children with and without symptoms – symptoms ever (as % of total number of returned questionnaires)

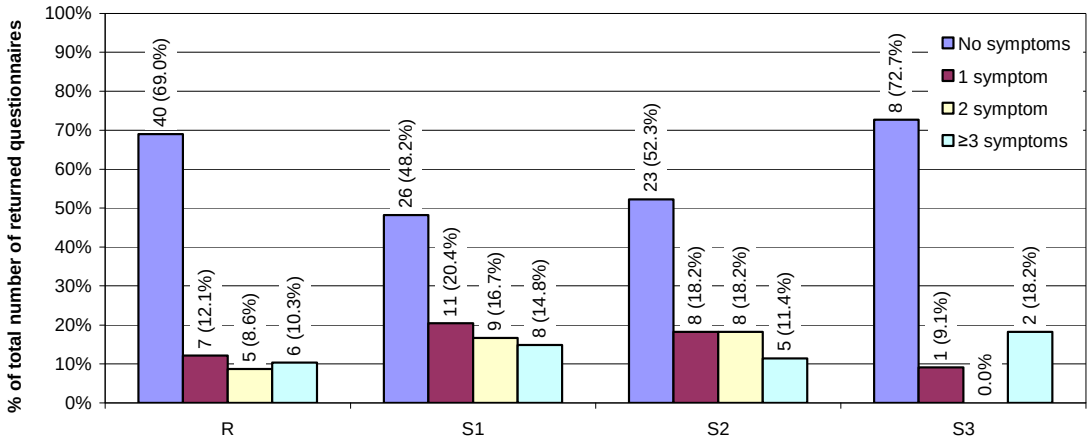


Figure 26 Propitiations of children with and without symptoms – symptoms in the last 12 months (as % of total number of returned questionnaires)

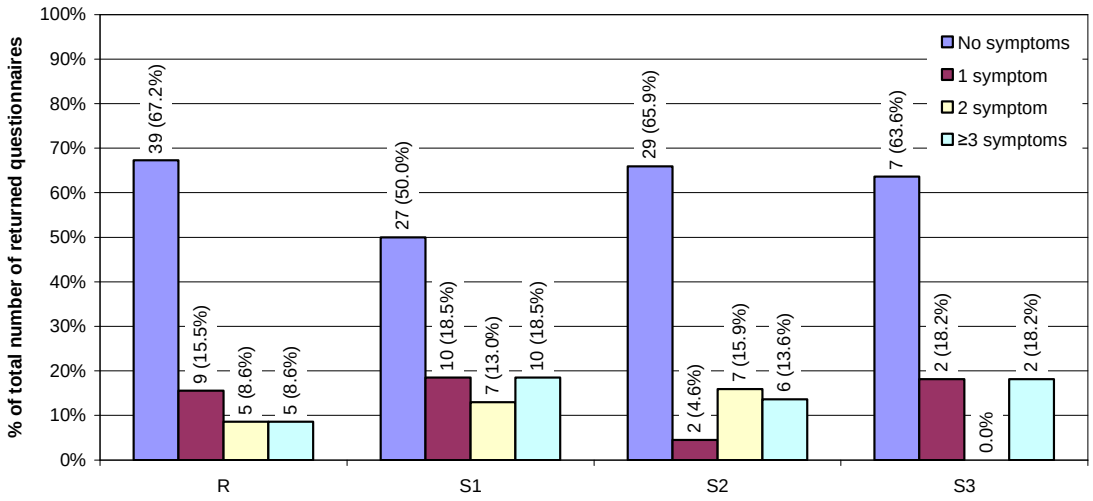


Figure 27 Mean modelled personal exposures of Class A (means across seasons, by school)

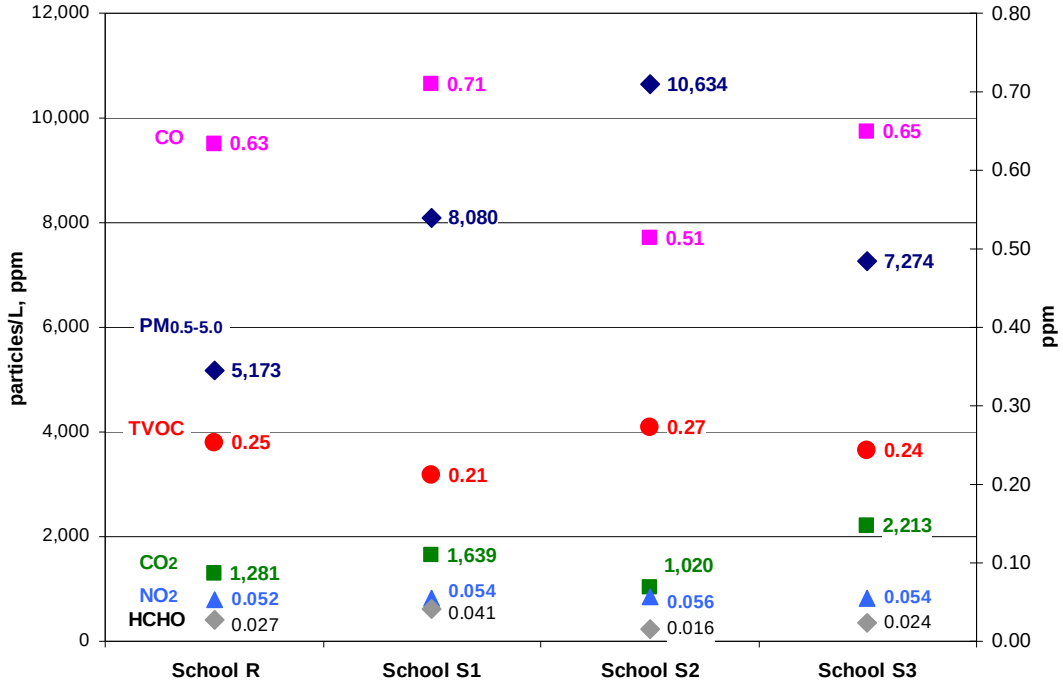


Table 26 Mean modelled personal exposures of Class A (with standard deviations) – means across seasons, by school

	School R		School S1		School S2		School S3	
Pollutant	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
$PM_{0.5-5.0}$ (particles/L)	5,173	2,301	8,080	6,350	**10,634**	12,781	7,274	4,030
CO (ppm)	0.63	0.66	**0.71**	0.47	0.51	0.16	0.65	0.27
NO_2 (ppb)	52	7	54	9	**56**	8	54	11
TVOC (ppm)	0.25	0.24	0.21	0.29	**0.27**	0.26	0.24	0.17
HCHO (ppb)	27	26	**41**	75	16	14	24	24
CO_2 (ppm)	1,281	765	1,639	1,148	1,020	472	**2,213**	1,462

Note: In bold are the highest overall PE means for each pollutant, out of the four school means. Overall PE means were calculated from the modelled PE data from all available seasons of measurements – 2 seasons for School R and 3 seasons for schools S1, S2 and S3 (only measurements taken during the occupied part of the day – 8:30 to 15:30 – were considered).

Table 27 Number and percent of cases when indoor daily means (ME) exceeded guideline values

Season	School	NO_2 > 50 ppb		CO_2 > 1,500 ppm		CO_2 > 3,500 ppm		HCHO > 0.04 ppm	
		No.	%	No.	%	No.	%	No.	%
Autumn	R	2	13	2	13	0	0	–	–
	S1	6	40	11	73	0	0	–	–
	S2	10	67	0	0	0	0	–	–
	S3	2	13	10	67	5	33	–	–
Winter	S1	2	13	10	67	0	0	–	–
	S2	4	27	4	27	0	0	–	–
	S3	10	67	10	67	4	27	–	–
Summer	R	4	27	3	20	0	0	2	13
	S1	5	33	4	27	0	0	5	33
	S2	8	53	0	0	0	0	0	0
	S3	6	40	7	47	0	0	2	13

Notes: The total number of cases is 15 per school per season – 3 indoor locations by 5 days of measurement.
Daily means are averages over the occupied part of the day: 8:45 to 15:30.
NO_2 guideline is a 24-hour average (Health Canada).
CO_2 guideline of 1,500 ppm is a school day average (Building Bulletin 101, UK).
CO_2 guideline of 3,500 ppm is a 24-hour average (Health Canada).
HCHO is an 8-hour average (Health Canada).

Table 28 Number and percent of cases when PE daily means exceeded guideline values

Season	School	NO2 > 50 ppb		CO2 > 1500 ppm		CO2 > 3500 ppm		HCHO > 0.04 ppm	
		No.	%	No.	%	No.	%	No.	%
Autumn	R	4	80	1	20	0	0	–	–
	S1	8	80	6	60	0	0	–	–
	S2	9	90	0	0	0	0	–	–
	S3	4	40	10	100	0	0	–	–
Winter	S1	4	40	10	100	0	0	–	–
	S2	8	80	2	20	0	0	–	–
	S3	7	70	9	90	0	0	–	–
Summer	R	3	60	1	20	0	0	0	0
	S1	6	60	3	30	0	0	5	50
	S2	8	80	0	0	0	0	0	0
	S3	9	90	7	70	0	0	1	10

Notes: The total number of cases is 10 for schools S1, S2 and S3 (2 classes by 5 days of measurement) and 5 for School R (1 class by 5 days of measurement) per season.
Daily means are averages over the occupied part of the day: 8:45 to 15:30.
NO_2 guideline is a 24-hour average (Health Canada).
CO_2 guideline of 1,500 ppm is a school day average (Building Bulletin 101, UK).
CO_2 guideline of 3,500 ppm is a 24-hour average (Health Canada).
HCHO is an 8-hour average (Health Canada).

Table 29 Numbers and percentages of indoors ME observations exceeding guideline values for TVOC in the summer round of measurements

School	Location	> 0.0652 ppm			> 0.163 ppm		
		Y / N	No of observations	%	Y / N	No of observations	%
R	Classroom A	NO	0	0	NO	653	32
		YES	2,018	100	YES	1,365	68
	Corridor	NO	0	0	NO	664	33
		YES	2,018	100	YES	1,354	67
	Hall	NO	0	0	NO	0	0
		YES	2,017	100	YES	2,017	100
S1	Classroom A	NO	1,001	52	NO	1,634	84
		YES	939	48	YES	306	16
	Classroom B	NO	0	0	NO	1,361	70
		YES	1,957	100	YES	596	30
	Hall	NO	0	0	NO	460	24
		YES	1,949	100	YES	1,489	76
S2	Classroom A	NO	138	7	NO	868	43
		YES	1,886	93	YES	1,156	57
	Classroom B	NO	0	0	NO	0	0
		YES	2,023	100	YES	2,023	100
	Hall	NO	0	0	NO	50	2
		YES	2,024	100	YES	1,974	98
S3	Classroom A	NO	338	17	NO	711	36
		YES	1,647	83	YES	1,274	64
	Classroom B	NO	0	0	NO	379	19
		YES	2,008	100	YES	1,629	81
	Hall	NO	0	0	NO	255	13
		YES	1,962	100	YES	1,707	87

Notes:
NO – observations do not exceed the guideline value;
YES – observations exceed the guideline value.
Only the measurements covering the occupied part of the day (8:45 to 15:30) are presented.
TVOC maximum acceptable concentration guideline of 200 $\mu g/m^3$ (0.0652 ppm) by the Finnish Society of IAQ and Climate;
TVOC maximum acceptable concentration guideline of 500 $\mu g/m^3$ (0.163 ppm) by the Australian National Health and Medical Research Council.

Table 30 Numbers and percentages of PE observations exceeding guideline values for TVOC in the summer round of measurements

School	Location	> 0.0652 ppm			> 0.163 ppm		
		Y / N	No of observations	%	Y / N	No of observations	%
R	Class A	NO	156	8	NO	665	33
		YES	1,862	92	YES	1,353	67
S1	Class A	NO	791	42	NO	1,190	63
		YES	1,101	58	YES	702	37
	Class B	NO	257	13	NO	1,095	56
		YES	1,695	87	YES	857	44
S2	Class A	NO	204	10	NO	798	40
		YES	1,774	90	YES	1,180	60
	Class B	NO	127	6	NO	222	11
		YES	1,896	94	YES	1,801	89
S3	Class A	NO	420	21	NO	798	41
		YES	1,550	79	YES	1,172	59
	Class B	NO	228	12	NO	673	34
		YES	1,751	88	YES	1,306	66

Notes: See notes to Table 29.

Appendix 1: Health and background questionnaire

SchoolAir

A Brunel University pilot study on indoor air quality in schools and asthmatic, respiratory and allergic symptoms in children

schoolair@brunel.ac.uk
www.etcbrunel.co.uk/schoolair
fax: 01895 269 761
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Brunel UNIVERSITY WEST LONDON

Brunel University
Kingston Lane
Uxbridge
UB8 3PH

A. Basic questionnaire

1. School class_____

Child's first name_____ Child's surname_____

2. Home address (street, postcode)_____

3. Date of Birth_____

4. Gender: FEMALE ☐ MALE ☐

5. Ethnicity of child:

Bangladeshi	☐	Indian	☐
Black-African	☐	Latin	☐
Black-Caribbean	☐	Pakistani	☐
Black-Other	☐	White	☐
Chinese	☐	Other / Mixed	☐
Don't know / prefer not to say			☐

B. Questionnaire on respiratory symptoms

6. Has your child ever had wheezing or whistling in the chest at any time in the past?

YES ☐ NO ☐

IF YOU ANSWERED **NO** PLEASE GO TO QUESTION 12

7. Has your child had any wheezing or whistling in the chest in the last 12 months?

YES ☐ NO ☐

IF YOU ANSWERED **NO** PLEASE GO TO QUESTION 12

8. How many attacks of wheezing has your child had in the last 12 months?

None	☐
1 to 3	☐
4 to 12	☐
More than 12	☐

9. In the last 12 months, how often, on average, has your child's sleep been disturbed due to wheezing?

Never woken up with wheezing	☐
Less that one night per week	☐
One or more nights per week	☐

10. In the last 12 months, has wheezing ever been severe enough to limit your child's speech to only one to two words at a time between the breaths?

YES ☐ NO ☐

11. In the last 12 months, what has made your child's wheezing worse? *(Please tick **all** that apply)*

Weather	☐	Wool clothing	☐
Pollen	☐	Colds or flu	☐
Emotion	☐	Cigarette smoke	☐
Fumes	☐	Foods or drinks	☐
Dust	☐	Soaps, sprays or detergents	☐
Pets	☐	Other things *(please list below)*	☐

---

12. Has your child ever had asthma?

YES ☐ NO ☐

13. In the last 12 months, has your child used any medicines, pills, puffers or other medication for wheezing or asthma?

YES ☐ NO ☐

14. In the last 12 months, has your child's chest sounded wheezy during or after exercise?

YES ☐ NO ☐

15. In the last 12 months, has your child had a dry cough at night, apart from a cough associated with a cold or chest infection?

YES ☐ NO ☐

16. In the last 12 months, how many times has your child been admitted to hospital because of wheezing or asthma?

None	☐
Once	☐
2 times	☐
More than 2	☐

C. Questionnaire on nose problems

*All questions are about problems which occur when your child **DOES NOT have a cold or flu***

17. Has your child ever had problems with sneezing, or a runny, or a blocked nose when they DID NOT have a cold or flu?

YES ☐ NO ☐

IF YOU ANSWERED **NO** PLEASE GO TO QUESTION 22

---

18. In the last 12 months, has your child had any problems with sneezing, or a runny, or a blocked nose when they DID NOT have a cold or flu?

YES ☐ NO ☐

IF YOU ANSWERED **NO** PLEASE GO TO QUESTION 22

19. In the last 12 months, has this problem been accompanied by itchy, watery eyes?

YES ☐ NO ☐

20. In which of the past 12 months did this nose problem occur? *(Please tick **all** that apply)*

January	☐	May	☐	September	☐
February	☐	June	☐	October	☐
March	☐	July	☐	November	☐
April	☐	August	☐	December	☐

21. In the last 12 months, how much did these nose problems interfere with your child's daily activities?

Not at all ☐ A little ☐ A moderate amount ☐ A lot ☐

22. Has your child ever had any hayfever?

YES ☐ NO ☐

D. General questionnaire

23. Does your child suffer from any other illnesses or diseases?

YES ☐ NO ☐

if YES please specify _____

24. If you answered "**YES**" to the previous question, does your child take any medication for this?

YES ☐ NO ☐

if YES please specify _____

25. Number of people at home_____

26. Is anyone smoking at home?

YES ☐ NO ☐

IF YOU ANSWERED **NO** PLEASE GO TO QUESTION 29

27. If you responded "**YES**" to the previous question, who smokes?

Mother ☐ Father ☐ Other ☐ How many people in all?_____

28. If anyone smokes at home, **how many cigarettes per day** do they usually smoke?
*(Please put a **number** in appropriate boxes)*

Mother ☐☐ Father ☐☐ Other 1 ☐☐ Other 2 ☐☐ Other 3 ☐☐

*(if "Other" please specify **who**)*_____

29. Does any member of the immediate family have asthma?

YES ☐ NO ☐

if YES please specify who (mother, father, sister, brother, etc.)_____

30. Does any member of the immediate family have any allergies?

YES ☐ NO ☐

if YES please specify who (mother, father, sister, brother, etc.)_____

31. Do you have pets in the house? *(Please tick **all** that apply)*

Dog	☐	Bird	☐
Cat	☐	Others *(please specify)*	☐
Other furry animals	☐	No pets at home	☐

32. What type of flooring do you have in your child's bedroom?

Carpet	☐
Wooden floor	☐
Linoleum	☐
Other *(please specify)*	☐

33. Which of the following do you use for heating? *(Please tick **all** that apply)*

Gas central heating	☐	Fan heater	☐
Gas fires	☐	Electric heater	☐
Paraffin heater (space heater)	☐	Other *(please specify)*	☐

34. Which of the following do you use for cooking? *(Please tick **all** that apply)*

Gas hob	☐	Electric oven	☐
Electric hob	☐	Microwave oven	☐
Gas oven	☐	Other *(please specify)*	☐

35. Are there any damp spots or visible moulds or fungus on the walls or ceiling in your home?

YES ☐ NO ☐

36. How would you describe surroundings of your home?

Urban with no parks or gardens	☐
Suburban, with few parks and gardens	☐
Suburban, with many parks and gardens	☐
Rural, open spaces and fields nearby	☐

37. On average, how many hours per day does your child usually spend outdoors?

On a week day _____ (hours)

On a weekend day _____ (hours)

38. What means of transport do you use more frequently to take your child to school?
*(if you use several, please tick the **one** that **takes longest per day**)*

Car	☐	Train	☐
Bus	☐	Walking / Cycling	☐
Underground	☐	Other	☐

39. For how long did the child's parents / guardians attend school or professional training?

	Mother / guardian	**Father / guardian**
School	_____ years	_____ years
College / University	_____ years	_____ years

40. What is the occupation of child's parents / guardians?

Mother / guardian _____

Father / guardian _____

41. Who has answered this questionnaire? Mother ☐ Father ☐ Other ☐

(if "Other" please specify) _____

42. When was the questionnaire answered? _____/_____/_____
Day / Month / Year

Thank you very much for completing this questionnaire!

Please return it to your child's teacher in the envelope provided

Appendix 2: Consent form and supplementary information sheets

SchoolAir

A Brunel University pilot study on indoor air quality in schools and asthmatic, respiratory and allergic symptoms in children

schoolair@brunel.ac.uk
www.etcbrunel.co.uk/schoolair
fax: 01895 269 761
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Indoor air quality and respiratory health of children: a pilot study of primary schools

Consent form

I agree for my child/children to take part in this research study and agree that my child/children can participate in breath measurement tests*. I have discussed this with my child/children, who is/are happy to take part. (A child-friendly information sheet is provided with this form.)

I understand that information will be collected on the health status of my child/children and some information will be gathered about the parents/guardians. I understand that information collected will be used only for the purpose of this research. I understand that the data will be reported in aggregate form, and no individual information (names, address) will be reported or published. I understand that if I wish I may withdraw at any time of the study. I have read the Research Participant Information Sheet and have received satisfactory answers to any questions I have about this research.

Signature of parent / guardian _____
Date_____

Name of child / children _____ _____

Date of birth of child / children _____ _____

**You can delete some of this sentence if you only want to participate in one part of the project.*

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You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask us if there is anything that is not clear or if you would like to get more information. Take time to decide whether or not you wish to take part.

Indoor air quality and respiratory health of children: a pilot study of primary schools

Research Participant Information Sheet

The Institute for the Environment and the Experimental Techniques Centre at Brunel University are conducting a study to look at the relationship between air quality in schools and occurrence of respiratory and allergic symptoms of children of junior level.

Prevalence of respiratory and allergic diseases in children in the UK has been increasing in the past two decades, and the issue is of great public health concern. Although it is not very clear what causes asthma or allergic diseases, there are a number of environmental factors such as particulate matter, gaseous pollutants, or allergens (pollen, dust mites) that may contribute to the development of the disease, and these are commonly found in indoor environments. Children in the UK spend about a third of their day indoors in schools, therefore we want to investigate the school environments to get a better understanding of children's total exposure to allergens.

The study is gathering information in three ways:

1. **Measurements of air quality** in classrooms, and throughout the school

2. **Collection of information via questionnaires to parents/guardians**, asking about asthma and allergic disease symptoms among their children, and some information about relevant family background (such as smoking levels)

3. **Simple measurements of child breath chemistry**: we shall ask each child to breathe out into a tube so that this air can be analysed

The findings of the pilot study will be used to help improve understanding of air quality in the schools, and inform the course of future research.

How will the project work in my child's school?

This project will run from August 2009 to July 2010, thus covering the whole school year.

You will be sent a questionnaire to complete in September/October 2009 and throughout the year there will be four one-week visits, during which the research team will be conducting measurements in schools. You will be sent brief update questionnaires to coincide with these measurement visits.

Children's breath will be analysed at the beginning and end of the project, twice during the first visit (Autumn 2009) and twice in the last week (Summer 2010). This will be done away from the classroom by research team members who have undergone enhanced CRB checks.

Who will see the information I provide?

All information which is collected about you and your child during the course of the research will be kept strictly confidential to the research team and will not be disclosed to the school. Reports and scientific publications may arise from this work. All data used in such reports will be in aggregate form identifying trends in the data, no child names or addresses will be reported or published. It is expected that this data will help develop a larger scale project. Except in the reported form, data will not be retained for longer than ten years from the end of the study.

What happens if I don't want to take part?

As participation is entirely voluntary, it is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. Your decision to take part or not take part will not affect your child's grades or treatment at school.

How do I get more information?

There are details of the project on our website *www.etcbrunel.co.uk/schoolair.htm*

You can also contact the research team by e-mailing *SchoolAir@brunel.ac.uk*; or contact individual SchoolAir team members directly:

Dr Ariana Zeka MD ScD, Principal Investigator, Institute for the Environment
ariana.zeka@brunel.ac.uk *tel:* 01895 267359 *dept:* 01895 266105 *fax:* 01895 269761

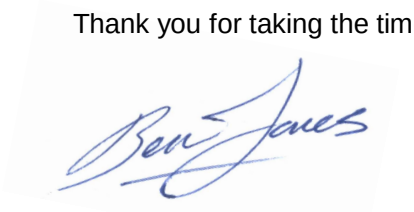
Dr Benjamin Jones PhD MIPEM CPhys, Principal Investigator, Experimental Techniques Centre
bj.jones@brunel.ac.uk *tel:* 01895 265409 *dept:* 01895 255793 *fax:* 01895 812544

Yulia Anopa BSc, MSc, MSc, Research Scientist, SchoolAir Project
yulia.anopa@brunel.ac.uk *mob:* 07717 818797

This project has been approved by the Research Ethics Committee at Brunel University, chaired by David Anderson-Ford. If you have any issues that cannot be resolved by the research team, you can contact the ethics committee directly:

David Anderson-Ford
Chair of Ethics Committee
Brunel University
Kingston Lane
Uxbridge
UB8 3PH

Thank you for taking the time to help with our research



Dr Benjamin Jones

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INFORMATION FOR PUPILS

A group of scientists from Brunel University in London are coming to school this year as part of a study into air and breathing. The team will measure the air while you work at your usual lessons, and they will ask your parents some questions about asthma and wheezing.

We would also like to ask some of you to help with this work – pupils in year three will be asked to blow into a special tube two times over a week as a way to measure chemicals in breath. We would like people to help with this so that we know more about why some children get asthma.

It is totally up to you whether or not you would like to take part, please talk to your parents about this. If you have any questions, ask your parents to e-mail us at SchoolAir@brunel.ac.uk, or talk to us in school.

SchoolAir

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Brunel UNIVERSITY WEST LONDON

Brunel University
Kingston Lane
Uxbridge
UB8 3PH

Dear Parents / Guardians,

A Survey of Breathing and Nose Problems is aimed at obtaining certain range of data, such as children's age, wheezing or other respiratory symptoms, nose problems, home environments, etc., for our SchoolAir project. The data collected will be kept strictly confidential to the research team and will not be disclosed to the school. Every question in the questionnaire is very useful for the purpose of this research. However, if there is anything you do not wish to answer, please leave this blank and continue to the next question.

The questions are grouped into four sections:

A. Basic questionnaire (contains questions such as name, school class, date of birth, gender of your child, etc.)

B. Questionnaire on respiratory symptoms

C. Questionnaire on nose problems

D. General questionnaire (this section contains questions on other illnesses of the child, tobacco smoke at home, questions on general home environment of the child, allergic and asthma issues in immediate family members, and some general questions on the mother and the father / guardians of the child)

Instructions to complete the questionnaire

There are three types of questions in this questionnaire:

1) Questions where you are asked to *write your answers in the space provided*:
For example.

School class: 3A

Child's first name John **Child's surname** Johnson

2) Questions that require you to *tick your answer in a box*. These questions may be classified into two groups:

- Questions *with one answer*

For example, **Has your child ever had asthma?** YES ☐ NO ☑

- Questions *with multiple answers*, where you can tick as many boxes as apply:

For example, **Do you have pets in the house?** *(Please tick all that apply)*

Dog	☑	Bird	☐
Cat	☐	Others	☐
Other furry animals	☑		

3) Questions, where you require to tick a box *and* specify in the space provided:
For example, **Does any member of the immediate family have any allergies?**

YES ☑ NO ☐

if YES please specify who (mother, father, sister, brother, etc.) _mother and brother___

Once you have filled in the questionnaire, please put it in the envelope provided, seal it and return to your child's teacher at school.

Please remember to sign the consent form!