World Health Organization
REGIONAL OFFICE FOR Europe

Literature review on chemical pollutants in indoor air in public settings for children and overview of their health effects

with a focus on schools, kindergartens and day-care centres

Supplementary publication to the screening tool for assessment of health risks from combined exposure to multiple chemicals in indoor air in public settings for children

Abstract

This publication summarizes the scientific information on children's health outcomes related to exposure to chemical pollutants in indoor air in public settings; on chemicals that are commonly detected in indoor air in schools, kindergartens and day-care centres; and on the likelihood of co-occurrence of these chemicals. It served as a background document to facilitate the selection of priority adverse effects (health endpoints) and chemicals to be included in the WHO Regional Office for Europe's screening tool for assessment of risks from combined exposure to multiple chemicals in indoor air in public settings for children.

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CONTENTS

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LIST OF ABBREVIATIONS

ASD	autism spectrum disorder
BDE	brominated diphenyl ether
BREATH	Brain Development and Air Pollution Ultrafine Particles in School Children
CAS	Chemical Abstracts Service
CO	carbon monoxide
CO_2	carbon dioxide
DBP	dibutyl phthalate
DEHP	di(2-ethylhexyl) phthalate
DEP	diethyl phthalate
DiBP	diisobutyl phthalate
DnBP	di-n-butyl phthalate
DOI	digital object identifier
ECA	European Collaborative Action
EDC	endocrine-disrupting chemical
EnVIE	Co-ordination Action on Indoor Air Quality and Health Effects
FEV1	forced expiratory volume
FVC	forced vital capacity
HCH	hexachlorocyclohexane
HESE	Health Effects of School Environment
HESEINT	Interventions on Health Effects of School Environment
IARC	International Agency for Research on Cancer
IPCS	International Programme on Chemical Safety
IQ	intelligence quotient
LOD	limit of detection
LOQ	limit of quantification
NA	not applicable
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
OxyVOC	oxygenated volatile organic compound
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PM	particulate matter

ABBREVIATIONS contd.

$PM_{2.5}$	particulate matter with a diameter of less than 2.5 μm
PM_{10}	particulate matter with a diameter of less than 10 μm
PPM	parts per million
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SEARCH	School Environment and Respiratory Health of Children
SINPHONIE	Schools Indoor Pollution and Health Observatory Network in Europe
SO_2	sulfur dioxide
SVOC	semi-volatile organic compound
TRAP	traffic-related air pollution
VOC	volatile organic compound

BACKGROUND

Children are exposed to different environmental factors in places where they learn and live that can have a profound influence on their health, growth and development. Quality of indoor air is one of the determinants of children's health and well-being, and a priority for public health *(1,2).*

Indoor air pollution in public settings depends on many factors: geographical conditions; penetration of outdoor air pollutants; emissions from building materials and other products used indoors; type of activities; and ventilation rate *(3)*. A broad list of pollutants in air inside buildings has been investigated and reported in studies. Pollutants found in the air in schools and other public settings for children include particulate matter (PM), volatile and semi-volatile organic compounds (VOCs and SVOCs), polycyclic aromatic hydrocarbons (PAHs), aldehydes, musks, phthalates, inorganic chemicals (carbon dioxide (CO_2), nitrogen dioxide (NO_2), ozone (O_3)), and other organic and inorganic compounds, among which are well known allergens, irritants and carcinogens. In studies of air pollution in European schools, kindergartens and day-care centres conducted between 2012 and 2017, around 90 chemical pollutants were identified. Concentrations exceeding national and international reference values were often reported.

Evidence of linkages between health impacts and exposure to both individual chemicals and mixtures of pollutants is reported in many studies. Exposure to indoor air pollution is associated with a variety of health problems in children, including effects on respiratory, nervous and immune systems and impairment of cognitive development. It can also increase risks of health impairments later in life, including cardiovascular diseases or cancer *(3–7)*. Links between poor indoor air quality and adverse health outcomes have been demonstrated in national and international research projects, such as School Environment and Respiratory Health of Children (SEARCH) *(8)*, Interventions on Health Effects of School Environment (HESEINT) *(9)*, and Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE) *(3)*, as well as other studies conducted in the WHO European Region and globally.

Simultaneous exposure to multiple substances is of high relevance in public settings for children, given the co-occurrence of chemicals and the time spent indoors. Additive effects and higher health risks from combined exposures cannot be excluded *(10),* as a number of studies of combined exposure to so-called chemical families (PAHs, VOCs) and their health effects have demonstrated *(11–14)*.

To advance assessment of risks of chemicals and to move away from a single-chemical-based approach, the WHO–International Programme on Chemical Safety (IPCS) developed a framework for assessment of risks from combined exposure to multiple chemicals *(15)*. This framework served as the basis for developing a WHO screening tool for assessment of health risks from combined exposure to selected chemicals in indoor air in public settings for children (schools, kindergartens and day-care centres) *(16).*

This publication was prepared in the context of the work on the screening tool, and served as a background document to facilitate the discussions of the expert group on the priority health outcomes and chemicals of concern *(17,18)*. It consists of three sections, each providing information which facilitated answering the following specific questions related to combined exposure risks assessment.

- *What health effects of indoor air pollution in schools and other public settings for children have been reported in epidemiological studies more commonly?* A summary of evidence of negative health impacts of indoor air pollution in public settings for children is presented in Section 1.
- *What chemicals are most commonly detected in air in schools, kindergartens and day-care centres?* A list of chemicals for consideration by the expert group based on a review of scientific publications is presented in Section 2.
- *Is co-exposure likely given the context and timeframe?* An analysis of co-occurrence of chemicals in air in schools, day-care centres and kindergartens is presented in Section 3.

Resource- and time-efficient approaches were applied to collect information needed to answer these questions and to underpin the development of the screening tool for assessment of risks from combined exposure to multiple chemicals in indoor air in public settings for children.

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SECTION 1: IMPACT OF INDOOR AIR CHEMICAL POLLUTION ON CHILDREN'S HEALTH

The evidence of the negative health impacts of pollutants in indoor air in public settings for children is growing. In 2014 the WHO Regional Office for Europe published an overview of combined exposure to multiple pollutants in indoor air in public settings for children *(1)*. This section summarizes the evidence collected between 2010 and 2019 of children's health effects from such exposures. It served as a scientific background for the selection of priority health endpoints in the process of the developing the screening tool *(2,3)*.

Scope

The starting point for scoping the work and collecting information on the effects of indoor air pollution on children's health were the results of European projects, including Co-ordination Action on Indoor Air Quality and Health Effects (EnVIE) *(4)*. Summarizing the findings of many studies, EnVIE concluded that the following diseases and symptoms are of particular interest in relation to poor indoor air quality: allergic sensitivity and asthma, lung cancer, chronic obstructive pulmonary disease, airborne respiratory infections, and irritation (sick building syndrome) *(5)*. Many other studies also stressed the link between these health disorders and indoor air quality, including in public settings for children.

This overview therefore focuses on respiratory and immune system disorders (acute and chronic) including asthma and allergic sensitivity; cardiovascular, nervous and endocrine system dysfunctions; and carcinogenicity. It focuses on studies related to combined exposure risks of indoor air pollutants in public settings for children, and also considers publications describing effects of individual chemicals and chemical families. Given the health relevance of exposure to PM, this overview also includes evidence of the effects on children's health linked to exposure to PM in public settings.[1]

Methods

The authors searched relevant publications in PubMed using the following keywords and their combinations: health risks, chemicals, chemical pollutants, cumulative risks, health effects, indoor air, schools, kindergartens, respiratory system, cardiovascular system, immune system, nervous system, neurological development, endocrine system, cancer.

In addition to evidence on health effects originating from epidemiological studies, information on adverse-effect endpoints of selected chemicals (see Section 2) from animal experiments was used to identify priority adverse-effect endpoints for grouping chemicals to assess risks from combined exposure.

[1] PM is complex mixture of organic and inorganic compounds rather than an individual chemical. As such, PM is not included in the assessment of health risks from combined exposure to multiple chemicals.

Effects on the respiratory system and allergic sensitization

Respiratory system disorders, both acute and chronic, due to indoor air pollution were reported in numerous studies of health effects from indoor air pollutants.

In the SEARCH project, both outdoor and indoor air pollutants (carbon monoxide (CO), CO_2, particulate matter 10 µm or less in diameter (PM_{10}), formaldehyde, NO_2 and VOCs) as well as temperature and relative humidity were monitored in 247 classrooms of 63 schools in 6 European countries. Increased levels of air pollutants in combination with insufficiency of natural ventilation were associated with higher rates of chronic bronchitis and asthmatic symptoms in children *(6)*.

A review of literature linking indoor air pollution with respiratory illnesses among school-aged children suggests that children living in households or studying in schools in urban areas are more likely to suffer from respiratory illnesses compared with children living or studying in rural areas *(7)*.

In the SINPHONIE project, the link between indoor air pollutants and health outcomes, assessed by a questionnaire and examination of respiratory system functions, was investigated in 114 schools in 23 countries. Strong association was reported between formaldehyde levels and dry throat, nasal allergy and phlegm in children. Exposure to VOCs was linked to allergic and respiratory symptoms (limonene: irritative cough; trichloroethylene and tetrachloroethylene: nasal allergy, wheezing). Exposure to indoor NO_2, particulate matter 2.5 µm or less in diameter ($PM_{2.5}$), and O_3 was associated with irritative cough. Furthermore, the link between O_3 concentration and wheezing (ever), nasal allergy (<12 months), doctor-diagnosed nasal allergy and asthma was observed *(8)*.

The cross-sectional European Union-funded Health Effects of School Environment (HESE) project looked at the effects of indoor air pollution on the respiratory health of schoolchildren in Denmark, France, Italy, Norway and Sweden *(9)*. Significantly lower nasal patency was observed in schoolchildren exposed to levels of PM_{10} higher than 50 µg/m^3 than in those exposed to lower levels.

A French study *(10)* related concentrations of air pollution in schools to skin-prick tests, prevalence of exercise-induced and reported asthma, and allergies in 6683 children (9–11 years old) attending 108 randomly selected schools. The results revealed that asthma (exercise-induced, past year and lifetime) was strongly positively associated with indoor concentrations of benzene, sulfur dioxide (SO_2), PM_{10}, the nitrogen oxides most relevant to air pollution (NO_x) and CO, while lifetime allergic rhinitis was linked with PM_{10}, and sensitization to pollens was associated with benzene and $PM_{10.}$

In the study of Annesi-Maesano et al. *(11)*, an increased prevalence of past-year allergic asthma in relation to exposure to high concentrations of $PM_{2.5}$, acrolein and NO_2 in the classrooms was observed. In addition, strong positive correlation between exercise-induced asthma and concentration of $PM_{2.5}$ and acrolein was reported.

Wallner et al. *(12)* studied air pollution (different chemical classes, biological allergens and thermal comfort) in schools in Austria in relation to its effect on lung function. A negative association was found between airflow in the lungs of schoolchildren and presence of formaldehyde in the air, and benzyl butyl phthalate and the sum of polybrominated diphenyl ethers in dust. Concentrations of ethylbenzene, m,p-xylenes and o-xylene negatively correlated with forced vital capacity (FVC) and forced expiratory volume (FEV1) in the first second. Chen et al. *(13)* also observed adverse effects on children's respiratory system, such as decreased lung function tests (FEV1 and FVC), associated with indoor air pollution.

Associations of lifetime asthma with exposure to PM and formaldehyde, rhinitis with total VOCs, and lower respiratory symptoms with formaldehyde levels, as well as potential more significant risks for children's health from combined exposure to these compounds, were also reported *(1,11).*

In Portugal, VOCs, aldehydes, $PM_{2.5}$, PM_{10}, bacteria, fungi, temperature and relative humidity levels were measured simultaneously both indoors and outdoors during a five-day period in 73 classrooms of 20 schools. In total, 978 children (8–10 years old) were involved in the study. Lung function (spirometry tests) and exhaled nitric oxide (NO) were investigated in 761 and 318 children, respectively. According to the results, despite no classrooms presenting concentrations of individual VOC pollutants exceeding the WHO indoor air quality guidelines *(14)* or the INDEX recommendations *(15)*, children exposed to higher total VOC concentrations had a two-fold increased risk of having asthma-related symptoms. These findings were supported by the results of spirometry and exhaled NO tests indicating chronic airway inflammation. $PM_{2.5}$ mass concentration levels inside and outside of day-care centres were associated with airway inflammation in preschool children, measured by fractional exhaled NO *(16)*. Residential proximity to industrial sites associated with high VOC levels represented a significantly higher risk of not attending school due to sore throat, cough and cold compared to non-exposed groups *(17)*.

As reported by European Collaborative Action (ECA), chemicals that might play an important role in triggering asthma symptoms include formaldehyde, aromatic and aliphatic chemical compounds, and phthalates or emissions from plastic materials *(18)*. Indoor chemical products resulting from ozonolysis of terpenes may also play a role, but the evidence is more limited *(18).* NO_2, PM, VOCs and formaldehyde in combination with dust mites, bacteria and fungal endotoxins may also increase the risk of development of asthma and wheeze in children *(19).* Higher $PM_{2.5}$ and PM_{10} mass concentration levels increased the odds of asthma-like symptoms *(20)*. Exposure to PAHs has also been linked to asthma development and exacerbation through promoting oxidative stress and immune responses *(21)*.

In summary, the most frequently reported adverse-effect endpoints of indoor air pollutants in the respiratory system of children include allergic rhinitis, asthma development or exacerbation (expressed as reported past-year or lifetime asthma, exercise-induced asthma, hospital admissions and emergency visits for asthma, asthma-like symptoms, wheezing, increased bronchial responsiveness), chronic airway inflammation (expressed as decreased lung function, decreased index of FEV1 and FVC detected by spirometry, enhanced exhaled NO), chronic bronchitis, and acute respiratory infections (pneumonia hospitalization).

Effects on the nervous system

Development of the nervous system (proliferation, migration, differentiation, myelinization of neurons, synaptogenesis and regulated apoptosis) extends from the embryonic period through adolescence *(22)*. This is a critical developmental window, when exposure to chemicals including from those in indoor air can result in neurodevelopmental disorders.

Known neurotoxic chemicals detected in indoor air are certain VOCs and PAHs. VOCs investigated in schools were found to be risk factors for the development of sick building syndrome, characterized by headache and fatigue *(23)*. Exposure to PAHs, in particular to benzo[a]pyrene, in the school environment during preadolescent school age was associated with subclinical changes on the caudate nucleus revealed in magnetic resonance imaging. This can play a crucial role in many cognitive and behaviour processes *(24)*.

In the Brain Development and Air Pollution Ultrafine Particles in School Children (BREATH) cohort study in Barcelona, Spain, conducted in 39 schools exposed to high or low traffic-related air pollution (TRAP), 2715 children 7–10 years old were tested four times via computerized tests. Air pollution monitoring (elemental carbon, NO_2 and ultrafine particles with a diameter of 10–700 nm) was conducted outdoors and indoors in two separate one-week campaigns in each school. Cognitive development was assessed through working memory and inattentiveness tests. After adjusting to age, sex, maternal education, socioeconomic status and air pollution exposure at home, the study found that children from the schools with higher levels of air pollution had significantly lower growth of cognitive development during 12 months than children from the schools with lower levels of pollution *(25)*. This negative association persisted during a three-and-a-half-year period *(26)*. In another study based on the BREATH cohort, annual average concentrations of PAHs, elemental carbon and NO_2 at the children's schools were associated with smaller caudate nuclei volumes and higher scores of behavioural disorders.

The observed effects depend on other characteristics (genetic) of children: lower improvement in inattentiveness over time in children carrying the *APOE* ε4 allele than in other children suggests that ε4 carriers may be more vulnerable to adverse neurobiological effects of TRAP exposure than non-carriers. That means that genetic factors could modify cognitive and other brain functions in response to exposure to indoor air pollutants *(27)*.

Suades-Gonzalez et al. *(28)* reviewed 31 epidemiological studies of exposure to air pollutants and neuropsychological development outcomes (delay of cognitive and psychomotor development, intelligence quotient (IQ), learning disabilities, reading comprehension, memory functions, speed of reactions, attention, coordination, perceptual coding, span length) and behaviour outcomes (attention disturbance, autistic traits, autism spectrum disorder (ASD)). Sufficient evidence of relations between pre- or postnatal exposure to PAHs and decreased IQ and between exposures to $PM_{2.5}$ and ASD was reported, whereas limited evidence of linkages between NO_x and ASD were observed.

A study conducted in China looked for linkages between indoor air concentrations of NO_2 and PM_{10} in a school located in an area with severe TRAP and a school with predicted low traffic density based on ambient air quality monitoring data and neurodevelopment of children (282 pupils were examined). In multiple ordinal logistic regression models after adjusting for other covariates (household pollution, demographics, birth weight, delivery method, breastfeeding, vision, familiarity with computer games) indoor TRAP exposure was significantly associated with poorer performance on neurobehavioural tests *(29)*.

According to several epidemiological and animal studies, early-life exposure to phthalates, bisphenol A, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and PAHs (contaminants that are often present in indoor air) may result in neurodevelopmental deficits, either via oxidative stress and neuroinflammation or interference with hormones during neural development *(30–33)*.

In summary, exposure to indoor air pollutants can negatively affect neuropsychological development measured as cognitive and psychomotor development, IQ, learning abilities, reading comprehension, memory functions, reading and math scores, reaction speed, attention, coordination, perceptual coding and span length.

Effects on the cardiovascular system

The evidence on the relationship between long-term exposure to air pollution, in particular to PM and cardiovascular mortality, is well established based on studies in adult populations. Much less is known about the association between air pollution and changes in cardiovascular parameters in children.

The few studies performed in the school environment *(34,35)* confirm that exposure to indoor air pollutants in homes and schools might contribute to the development of long-term health effects in the cardiovascular system. For example, later-life hypertension can correlate with higher blood pressure in early life. A review of the studies published between 2007 and 2017 that examined prenatal or childhood exposure to PM_{10} and $PM_{2.5}$, NO_x, O_3, black carbon, environmental tobacco smoke and phthalates reported associations between exposure to these pollutants and increased childhood blood pressure *(36)*.

Sughis et al. *(35)* investigated blood pressure in children at schools located in areas characterized by low and high pollution. The study concluded that children living and attending school in an area of very high TRAP have a substantially higher arterial blood pressure compared to less exposed children. A randomized, double-blind crossover trial among healthy college students *(37)* also demonstrated that reduction of PM through the use of air purifiers leads to significant decreases of levels of stress hormones (cortisol, cortisone, epinephrine and norepinephrine), blood pressure, insulin resistance, and biomarkers of oxidative stress and inflammation. Children attending schools near an oil refinery with high PAH levels in ambient air had significantly higher systolic and diastolic blood pressure Z-scores than those of children attending schools with low PAH levels, with a 4.36-fold increase in prehypertension *(34)*.

In summary, there is evidence of functional changes to the cardiovascular system in schoolchildren associated with exposure to indoor air pollutants.

Carcinogenic effects

A growing body of research on linkages between indoor air pollutants and carcinogenicity risk suggests that early-life exposures may contribute to cancer development later in life.

Several VOCs found in indoor air, such as benzene, trichloroethylene and formaldehyde, have been classified as known human carcinogens (Group 1) by the International Agency for Research on Cancer (IARC) based on evidence from epidemiologic studies and animal data *(38)*, while styrene and tetrachloroethylene have been classified as possible or probable carcinogen for humans, respectively *(39)*. Benzene is toxic to the bone marrow and is associated with various haematological cancers *(40)*. Formaldehyde may cause nasal cancer and leukaemia *(38)*. Among PAHs, benzo[a]pyrene has been classified as a known human carcinogen, and naphthalene, chrysene, benzo[a]anthracene, benzo[k]fluoranthene and benzo[b]fluoranthene have been classified as possible carcinogens *(41).* They may induce cancer tumours, primarily in the lungs, skin, bladder, liver and stomach.

Sarigiannis et al. *(42)* demonstrated that in Europe, indoor VOCs and other compounds, including benzene, formaldehyde, toluene, xylenes, styrene, acetaldehyde, naphthalene, limonene, alpha-pinene and ammonia, originate mostly from indoor sources (primary indoor pollutants). Cancer risks posed by these chemicals due to indoor exposure were estimated to be up to three orders of magnitude higher than one in 1 million (the threshold of what is considered acceptable).

Young children living close to busy road can be at increased risk of developing leukaemia *(43,44)*. Two recent meta-analyses suggested a link between ambient exposure to TRAP during childhood and leukaemia risk in children *(45,46)*. Several indoor and outdoor hazardous pollutants may play a role in the etiology of childhood leukaemia *(47)*. Children (infants, children 6 and 15 years old) exposed to toxic substances in the air (for example, acetaldehyde, 1,3-butadiene, benzene, ortho-dichlorobenzene, toluene and PAHs) may have increased risk of certain brain tumours *(48,49)*.

A number of studies on exposure to air pollutants in schools and cancer risks, estimated based on child-specific benchmark levels, have been published during last decade.

Chan et al. *(50)* modelled the risks of cancer from exposures to VOCs in schools in the United States of America. The estimated cancer risks were about 10 per million, which was lower than the risk of cancer predicted for exposures to VOCs in households. Based on investigation of 38 VOCs in 34 early-childhood educational environments, Hoang et al. *(51)* concluded that child exposures to benzene, chloroform, ethylbenzene and naphthalene exceeded age-adjusted benchmark levels based on California's Proposition 65 guidelines (10^{-5} lifetime cancer risk) in 71%, 38%, 56%, and 97% of facilities, respectively. Sofuoglu et al. *(52)* investigated indoor concentrations of VOCs in Turkish primary schools and determined that formaldehyde was the substance of particular concern in terms of high chronic toxic and carcinogenic risks, followed by naphthalene, benzene and toluene.

In summary, some studies revealed the associations between exposure to certain pollutants in indoor air and risks of childhood leukaemia and some central nervous system tumours.

Effects on the endocrine system

Children are exposed to endocrine-disrupting chemicals (EDCs) through contaminated drinking-water and food, through dermal contact with these chemicals, and through breathing polluted air indoors. EDCs are present in indoor environments mostly in particulate forms and in dust. Phthalates, bisphenol A, PBDEs and PCBs, environmental phenols, dioxins, PAHs and perfluorocarbons often occur in indoor air of homes and classrooms *(53–55)*. Data collected by Oziol et al. *(56)* confirmed the presence of EDCs in a gaseous state and highlighted their indoor origin and concentration, especially in the cold season.

Evaluating the contribution of indoor air quality in residences to daily intake of phthalates in Japanese children, Yoshida et al. *(57)* concluded that inhalation did not seem to contribute very much as an absorption pathway of the phthalates. A study by Bekö et al. *(58)* of inhalation, dust ingestion and dermal absorption of diisobutyl phthalate (DiBP), benzyl butyl phthalate and di(2-ethylhexyl) phthalate (DEHP) in 431 Danish children 3–6 years old resulted in a different conclusion: exposures to phthalates present in the air and dust indoors meaningfully contribute to a child's total intake of certain phthalates.

Using a cumulative risk-assessment approach for evaluating the contribution of indoor air pollution by phthalates, Fromme et al. *(59)* investigated phthalates in indoor air and dust in

German day-care centres. Estimates using a cumulative risk-assessment approach for the sum of DEHP, di-n-butyl phthalate (DnBP) and DiBP, revealed that 20% of the children had concentrations exceeding the hazard index of one. However, the contribution of different phthalates in indoor air and dust varied significantly (24–70%). Mechanisms of action, adverse effects and dose–response relationships between exposure to these chemicals from air (indoor and outdoor) are poorly understood. As no systematic screening of common chemicals for endocrine-disrupting effects is currently underway, questions remain as to the health impacts of these exposures *(60)*.

Unfortunately, until now, evidence of health effects in children from pollution of indoor air in public settings is very limited and relates mainly to obesogenic effects of EDCs *(61,62)*. In Portugal, 815 children in 20 schools in Porto were involved in an investigation of exposure to EDC and the prevalence of asthma and obesity *(61)*. The results confirmed that even low levels of indoor exposure may influence the risk of asthma, respiratory symptoms and obesity.

In summary, EDCs in both air and dust can contribute to overall exposure. However, the evidence of health effects in children from exposure to EDCs in schools and day-care centres is limited.

Summary

This overview of the literature on health outcomes associated with indoor air pollution was prepared to support discussion and selection of priority adverse-effect endpoints for inclusion in the screening tool. In this context, the evidence was considered consistent for the association between air pollution and respiratory system effects (most often allergic rhinitis, asthma development or exacerbation, chronic airway inflammation, and acute respiratory infections) and nervous system effects (impairments in different neuropsychological development outcomes or effects on the nervous system observed by neuroimaging) in children.

Evidence of potential cardiovascular effects in children (for example, elevated blood pressure and heart rate, higher levels of stress hormones and biomarkers of oxidative stress) is more limited and less consistent.

Data on potential effects on the immune system of children are limited (except for asthma and allergic rhinitis described above), varied and difficult to interpret, due in part to the commonly nonspecific nature of the endpoints considered (for example, infections such as pneumonia or otitis media; absenteeism from school due to sore throat, cough and cold; development of allergies).

The following priority adverse-effect endpoints were identified for inclusion in the screening tool based on this literature review and through expert consultations *(2,3)*:

- respiratory
- cardiovascular
- nervous
- irritation
- carcinogenicity.

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SECTION 2: POLLUTANTS MOST COMMONLY DETECTED IN INDOOR AIR

A list of chemical pollutants in indoor air is broad: VOCs, SVOCs, PM, phthalates, musks, PAHs, brominated flame retardants, organophosphate flame retardants, chlorinated paraffins and inorganic compounds. These pollutants originate from outdoor and indoor sources, and their concentrations indoors are determined by many factors and vary significantly. Given the high health relevance of indoor air pollution, national monitoring programmes/studies have been conducted in many countries. A large number focus on chemicals expected to be released from the known indoor sources, such as VOCs and SVOCs. Given the unavoidable penetration of outdoor pollutants into indoor environments, studies also commonly include an assessment of the main pollutants of outdoor air (PM, NO, PAHs, etc.) *(1,2)*.

Scope

This literature review aimed at creating a list of chemicals most commonly detected in indoor air in public settings for children (schools, kindergartens and day-care centres), based on the review of studies conducted in the WHO European Region and published from 2012. The list was shared with the expert group to consider chemicals of concern for inclusion in the WHO screening tool for assessment of health risks from combined exposure to hazardous chemicals in indoor air, referred to earlier in this publication *(3,4)*.

Methods

Priority was given to the published reviews: Malliari *(5)*, Morawska *(6)* and Annesi-Maesano (SINPHONIE) *(7)*. Regarding the SINPHONIE project, results from the final report from 2014 were retrieved, with a total of 114 schools and 342 classrooms investigated across Europe. Peer-reviewed journal articles and conference papers were sought using Google Scholar, Scopus and Science. In total, more than 150 papers were reviewed.

The keywords for the sampling locations were “school” OR “kindergarten” OR “nursery” OR “day care”. The keywords regarding the target substances were “pollutant” OR “particle” OR “substance”. Overall, the keywords for the search were “indoor air quality” combined with (AND) the sampling location keywords and target substance keywords. For the purpose of this review, measurements in settled dust were excluded.

Several rejection criteria were defined for the overview:

- a substance-type criterion: bio-contaminants, radiation and tobacco smoke were excluded;
- a geographical criterion: only studies performed in European countries were retrieved; and
- a temporal criterion: only studies published between 2012 and 2017 were retrieved, including reviews dwelling on a much broader time period.

Among the more than 150 publications reviewed, 26 were selected *(1,2,5–28)* based on the following exclusion criteria.

- Among the selected articles, different words referred to public settings for children, such as elementary school, primary school, nursery school, kindergarten or day-care centre. Studies involving universities or engineering schools were excluded, as were those involving high and middle schools.
- Studies originating from specific contexts, for example, particle characterization near schools where the uncontrolled combustion of a tire landfill took place, or a school near a steel factory, were excluded as they may misrepresent the common situation depicted in this publication.
- Five studies that took place in facilities not used by children (for example, teaching rooms or laboratories at a university) were also excluded.

Regarding data compilation (see Annex 1), several parameters were retrieved from the articles when available:

- measured substances
- corresponding Chemical Abstracts Service (CAS) registration number
- type of building investigated (school, kindergarten or day-care centre)
- number of buildings investigated
- number of rooms (in each building or in total)
- measurement unit
- measurement data: minimum, maximum, arithmetic mean and median
- country where the measurements took place
- year when the measurements took place
- reference information: year of publication, authors, title and digital object identifier (doi).

In several cases, studies did not report all the requested data (measurement results, number of sampling location, sampling year, etc.). In order not to be too restrictive, the articles were considered as long as at least one of the following measurement values was given: minimum, maximum, arithmetic mean or median.

If data were not provided or were reported too partially (that is, distribution P_{25}, P_{75} and nothing else), or if only plots were given without thresholds or figure descriptions, they could not be considered for the compilation.

Lastly, some results were properly given but combined with other types of buildings, such as offices and/or homes. If it was not possible to obtain separate values specifically for schools, kindergartens or day-care centres, data were not considered.

Results

As a result, the search identified 90 substances prioritized by frequency of detection (see Table 1).

Table 1. List of the most commonly detected indoor air pollutants in public settings for children

No.	Substance (alphabetical order)	CAS number	No.	Substance (alphabetical order)	CAS number
1	1-butanol	71-36-3	34	CO	630-08-0
2	1,2,3-trimethylbenzene	526-73-8	35	d-limonene	5989-27-5
3	1,4-dichlorobenzene	106-46-7	36	Di-isodecyl phthalate	26761-40-0
4	4-(1,2-dibromoethyl)-1,2-dibromocyclohexane	3322-93-8	37	DEHP	117-81-7
5	4,4'-dichloro-diphenyltrichloroethane	50-29-3	38	Dibenz[a,h]anthracene	53-70-3
6	Acenaphthene	83-32-9	39	Dibenzo[a,l]pyrene	191-30-0
7	Acenaphthylene	208-96-8	40	DiBP	84-69-5
8	Acetaldehyde	75-07-0	41	Diethyl phthalate (DEP)	84-66-2
9	Alpha hexachlorocyclohexane (HCH) (or α-HCH)	319-84-6	42	Diisononyl phthalate	28553-12-0
10	Anthracene	120-12-7	43	Dimethyl phthalate	131-11-3
11	Arsenic	7440-38-2	44	DnBP	84-74-2
12	Brominated diphenyl ether (BDE) 28	41318-75-6	45	Ethylacetate	141-78-6
13	BDE 47	5436-43-1	46	Ethylbenzene	100-41-4
14	BDE 99	60348-60-9	47	Fluoranthene	206-44-0
15	BDE 100	189084-64-8	48	Fluorene	86-73-7
16	BDE 153	68631-49-2	49	Formaldehyde	50-00-0
17	BDE 183	207122-16-5	50	Galaxolide	1222-05-5
18	BDE 209	1163-19-5	51	Gamma HCH (or γ-HCH)	134237-52-8
19	Benz[a]anthracene	56-55-3	52	Heptane	142-82-5
20	Benzene	71-43-2	53	Hexabromobenzene	201-773-9
21	Benzo[a]pyrene	50-32-8	54	Hexaldehyde	66-25-1
22	Benzo[b+ j]fluoranthene	205-99-2/205-82-3	55	Indeno[1,2,3-cd]pyrene	193-39-5
23	Benzo[b+j+k]fluoranthene	205-99-2/205-82-3/207-08-9	56	Limonene	138-86-3
24	Benzo[e]pyrene	192-97-2	57	m,p-xylenes	108-38-3/106-42-3
25	Benzo[ghi]perylene	191-24-2	58	Methylacetate	79-20-9
26	Benzo[k]fluoranthene	207-08-9	59	n-butylbenzene	104-51-8
27	Benzyl butyl phthalate	85-68-7	60	n-decane	124-18-5
28	Butyl acetate	123-86-4	51	Naphthalene	91-20-3
29	Butyraldehyde	123-72-8	62	Nickel	7440-02-0
30	Cadmium	7440-43-9	63	NO_2	10102-44-0
31	Camphene	79-92-5	64	o-xylene	95-47-6
32	Carbon	124-38-9	65	O_3	10028-15-6
33	Chrysene	218-01-9	66	Particles (number)	–

Table 1 cont.

No.	Substance (alphabetical order)	CAS number	No.	Substance (alphabetical order)	CAS number
67	PCB 28	7012-37-5	79	Styrene	100-42-5
68	PCB 31	16606-02-3	80	Tetrachloroethylene	127-18-4
69	PCB 52	35693-99-3	81	Toluene	108-88-3
70	PCB 101	37680-73-2	82	Tonalide	21145-77-7
71	PCB 138	35065-28-2	83	Total suspended particles	–
72	Permethrin	52645-53-1	84	Tri-(2-butoxyethyl)-phosphate	78-51-3
73	Phenanthrene	85-01-8	85	Tributylphosphate	126-73-8
74	PM_1	–	86	Trichloroethylene	79-01-6
75	$PM_{2.5}$	–	87	Tris(1-chloro-2-propyl) phosphate	13674-84-5
76	PM_{10}	–	88	Tris(2-chloroethyl) phosphate	115-96-8
77	Pyrene	129-00-0	89	Ultrafine particles	–
78	SO_2	7446-09-5	90	α-pinene	80-56-8

To reduce the list of substances to consider, a prioritization process was applied following different criteria that fit the objectives and scope of the study:

- preselection based on WHO guidance and existing documents (that is, guidelines for indoor or ambient air quality);
- number of studies and measurements in European Union schools over the past years to spot the most common chemical pollutants; and
- expert judgment regarding toxicological or exposition potential.

A final list of 30 substances measured in 26 countries was considered for the selection of chemicals for inclusion in the screening tool for assessment of health risks from combined exposure to multiple chemicals in indoor air, based on frequency of their recording (see Table 2).

Table 2. List of 30 chemicals selected for further discussion

No.	Substance	Number of recordings	No.	Substance	Number of recordings
1	Formaldehyde	24	17	Limonene	4
2	NO_2	20	18	n-decane	4
3	PM_{10}	19	19	Acetaldehyde	3
4	$PM_{2.5}$	17	20	BDE 47	3
5	Benzene	11	21	Benzo(a)pyrene	3
6	O_3	10	22	Naphthalene	3
7	CO	7	xx	o-xylene*	3
8	m,p-xylenes	7	xx	d-limonene*	2
9	Styrene	7	23	Phenanthrene	2
10	Toluene	7	24	Trichloroethylene	2
11	1,4-dichlorobenzene	6	25	DEP	2
12	Ethylbenzene	6	26	DiBP	2
13	Butyl acetate	5	27	DnBP	2
14	Tetrachloroethylene	5	28	Galaxolide	1
15	α-pinene	5	29	SO_2	1
16	1,2,3-trimethylbenzene	4	30	Tonalide	1

* The two substances in grey font (o-xylene and d-limonene) are accounted respectively with m,p-xylenes and limonene.

The process for the selection of priority chemicals is described in the reports on the first and the second expert consultations *(3,4)*. The final list of chemicals included in the screening tool is also available in the publication on methods for sampling and analysis of chemicals *(29)*.

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SECTION 3: CO-OCCURRENCE OF CHEMICAL POLLUTANTS IN INDOOR AIR

According to the WHO–IPCS framework *(1)*, the potential impact of the co-occurrence of, and concomitant exposure to, multiple chemicals should always be taken into account in problem formulation for combined exposures risk assessment. A critical question in that context is whether or not the co-occurrence of chemicals is likely within a relevant timeframe.

Scope

Relevant literature was reviewed to answer the following question: *Do chemicals co-occur in indoor air in schools, kindergartens and day-care centres, based on the review of information on chemical pollutants in indoor air found in public settings for children?*

In the review, the frequency of detection was used as the best way to identify whether pollutants are present simultaneously in air samples. If the frequency of detection for a pollutant is lower than 100%, it means that it is not systematically present in the indoor air, according to the sampling and analytical methods used.

Methods

Peer-reviewed journal articles and conference papers were sought in the PubMed, Science Direct and Google Scholar search engines, with publication dates from 2014 until 30 October 2018 and without geographical limitation. Studies that presented data for at least two chemicals measured simultaneously in indoor air in schools (preschools or elementary schools) and day-care centres or kindergartens were analysed.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach *(2)* was used to identify selected studies.

The three following search strings were used in the search engines.

1. (“Indoor air” OR “indoor air quality”) AND (“air pollutants”) AND (“schools” OR “classroom” OR “preschools” OR “day-care center” OR “nursery”)
2. (“indoor air” OR “indoor air quality”) AND (“multipollutants” OR “multi-pollutants” OR “multipollution” OR “multi-pollution”) AND (“schools” OR “classroom” OR “preschools” OR “day-care center” OR “nursery”)
3. (“indoor air” OR “indoor air quality”) AND (“air pollutants”) AND (“co-occurrence”) AND (“schools” OR “classroom” OR “preschools” OR “day-care center” OR “nursery”).

Several parameters were retrieved from the articles:

- reference information: year of publication, authors, title, journal or book doi, etc.
- year when the measurements took place
- country where the measurements took place
- type of building investigated (that is, school, kindergarten or day-care centre)

- number of buildings investigated
- number of rooms (in each building or in total)
- number of air samples
- measured compounds
- frequency detection of the measured compounds (%)
- corresponding CAS registration number.

The frequencies of detection of each measured chemical were recorded to preview their simultaneous presence in air samples (see Table 3).

Table 3. Number of measured compounds in the reviewed studies according to chemical family

Chemical family (alphabetical order)	Number of measured compounds	Chemical family (alphabetical order)	Number of measured compounds
VOCs		SVOCs	
Alcohols	4	Brominated flame retardants	28
Aldehydes	15	Organophosphates	8
Alkanes	14	PAHs	19
Aromatic hydrocarbons	12	PCBs	9
Ester alcohols	2	Perfluorinated compounds	11
Esters	2	Phthalates	7
Glycol ether	1	Pyrethroids	5
Halogenated hydrocarbons	6	Musks	2
Ketones	4	Non-phthalate plasticizers	8
Siloxanes	3	Organochlorine pesticides	7
Terpenes	5		

Some studies did not report all the requested data (detection frequencies, number of sampling location, sampling year, etc.). If detection frequencies were not reported but the distribution (P_{25}, median P_{75}) and limit of detection were mentioned, an estimate of frequency (a range) of detection from the distribution was indicated in the file. If detection frequencies were not provided, studies could not be considered for the compilation.

Lastly, some results were properly given but combined with other types of building such as offices and/or homes. If it was not possible to obtain separate values specifically for schools, data were not considered.

In total, 1656 studies were identified in the search.

1. ("Indoor air" OR "indoor air quality") AND ("air pollutants") AND ("schools" OR "classroom" OR "preschools" OR "day-care center" OR "nursery")
    a. PubMed: 66 references
    b. Science Direct: 536 references
    c. Google Scholar: 1000 references

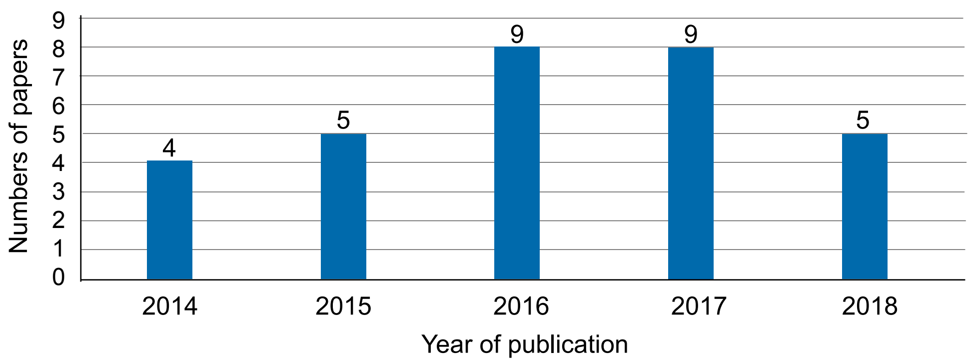
2. ("Indoor air" OR "indoor air quality") AND ("multipollutants" OR "multi-pollutants" OR "multipollution" OR "multi-pollution") AND ("schools" OR "classroom" OR "preschools" OR "day-care center" OR "nursery")
   a. PubMed: 2 references
   b. Science Direct: 21 references
   c. Google Scholar: 13 references
3. ("Indoor air" OR "indoor air quality") AND ("air pollutants") AND ("co-occurrence") AND ("schools" OR "classroom" OR "preschools" OR "day-care center" OR "nursery")
   a. PubMed: 0 references
   b. Science Direct: 5 references
   c. Google Scholar: 13 references

The first step of the reviewing process was to screen the titles and abstracts of these studies. As a result, 1585 papers were excluded according to the exclusion criteria mentioned above. Seventy-three studies were identified for full-text screening *(3–76).*

The second step was to remove irrelevant studies. Thirty-seven studies were removed because frequencies of detection or distributions were not provided, and five were removed because they took place in facilities not used by children (teaching rooms or laboratories at a university).

The number of selected studies published since 2014 was two times higher in 2016 and 2017 than in the other years (see Fig. 1). Twenty studies were carried out in schools (elementary or nursery) and 10 in day-care centres or children's facilities in 16 countries (Canada, China, France, Germany, Greece, Iran, Japan, Korea, Malaysia, Norway, Poland, Portugal, Serbia, Spain, Sweden and the United States of America).

Fig 1. Number of publications per year



The most measured chemical family was VOCs, which were included in 15 studies. This was followed by aldehydes (11 studies), PAHs (6 studies) and flame retardants (6 studies). In total, 177 pollutants were considered (see Table 3).

Summary

At least two chemicals were detected in all reviewed studies. No specific pairs or group of chemicals were identified. However, the likelihood of co-occurrence of multiple chemicals in indoor air in schools, kindergartens and day-care centres is high. This is a strong argument in favour of applying the WHO framework for assessment of risks from combined exposure to multiple chemicals *(1)* in indoor air in public settings for children.

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ANNEX 1: DATABASE OF CHEMICAL POLLUTANTS IN INDOOR AIR IN SCHOOLS, KINDERGARTENS AND DAY-CARE CENTRES

Table A1. Chemical pollutants in schools, kindergartens and day-care centres (2010–2017)[2]

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
					Oxygenated volatile organic compounds (oxyVOCs) – aldehydes						
1	**Formaldehyde (CAS 50-00-0)**										
	School	Not applicable (NA)	NA	μg/m³	12	–	28	55	NA	NA	Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S & on behalf of the SINPHONIE Group. Indoor air quality and sources in schools and related health effects. J Toxicol Environ Health B Crit Rev. 2013;16:8:491–550. doi:10.1080/10937404.2013.853609.
	School	NA	NA	μg/m³	–	–	21.5	–	NA	NA	
	School	NA	NA	μg/m³	0.3	7.8	4.8	85.8	NA	NA	
	School	NA	NA	μg/m³	2.21	35.13	–	68.04	NA	NA	
	School	NA	NA	μg/m³	4.05	30.34	–	56.62	NA	NA	
	School	NA	NA	μg/m³	3.81	40.04	–	76.2	NA	NA	
	School	NA	NA	μg/m³	12.9	–	–	47.3	NA	NA	
	Nursery school	2	1 playroom 1 classroom	mg/m³	0.01	0.035	–	0.09	Portugal	2013	Oliveira M, Slezakova K, Delerue-Matos C, do Carmo Pereira M, Morais S. Indoor air quality in preschools (3- to 5-year-old children) in the northeast of Portugal during spring–summer season: pollutants and comfort parameters. J Toxicol Environ Health A. 2017;80(13–15):740–55. doi:10.1080/15287394.2017.1286932.

[2] Chemicals agreed at the first expert consultation (3–4 December 2018) are included in the database.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
1	**Formaldehyde (CAS 50-00-0)**										
	Nursery school	46	1 or 2 in each	µg/m³	2.5	14	12	181	France	2009/2010	Ramalho O, Wyart G, Mandin C, Blondeau P, Cabanes P, Leclerc N et al. Association of carbon dioxide with indoor air pollutants and exceedance of health guideline values. Build Environ. 2015;93:115–24. doi:10.1016/j.buildenv.2015.03.018.
	Kindergarten	61	1 or 2 in each	µg/m³	2	22	19	98	France	2009/2010	
	Elementary school	53	1 or 2 in each	µg/m³	1.6	19	17	70	France	2009/2010	
	Nursery/ elementary school	17	51	µg/m³	6.8	25.1	19.2	66.2	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ ina.12222.
	School	114	300	µg/m³	1	15	12	66	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
	School	20	72	µg/m³	8.24	19.8	17.5	126.9	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
2	**Acetaldehyde (CAS 75-07-0)**										
	Nursery/ elementary school	17	51	μg/m³	2.7	6.3	6.1	10.7	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.
	School	20	72	μg/m³	1.92	9.31	7.65	64.6	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.
	Volatile organic compounds (VOCs) – aromatic hydrocarbons										
3	**Benzene (CAS 71-43-2)**										
	Nursery school	46	1–2 per building	μg/m³	0.7	2.5	2.3	6.5	France	2009/2010	Ramalho O, Wyart G, Mandin C, Blondeau P, Cabanes P, Leclerc N et al. Association of carbon dioxide with indoor air pollutants and exceedance of health guideline values. Build Environ. 2015;93:115–24. doi:10.1016/j.buildenv.2015.03.018.
	Kindergarten	61	1–2 per building	μg/m³	0.6	2.4	2.2	7.9	France	2009/2010	
	Elementary school	53	1–2 per building	μg/m³	0.2	2.5	2.2	21.7	France	2009/2010	
	Nursery school	1	2	μg/m³	–	2.745	–	–	Czechia	–	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
3	**Benzene (CAS 71-43-2)**										
	Nursery/ elementary school	17	51	µg/m³	< Limit of quantitation (LOQ)	2.1	1.4	8.5	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.
	School	114	300	µg/m³	< Limit of detection (LOD)	4	2	38	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
	Elementary school	1	3	µg/m³	0.55	–	–	0.65	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	µg/m³	0.47	–	–	1.09	Italy	–	
	Elementary school	1	3	µg/m³	0.11	–	–	0.25	Italy	–	
	Elementary school	1	3	µg/m³	0.04	–	–	0.11	Italy	–	
	School	20	72	µg/m³	1.5	2.2	2.5	2.7	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
4	**Ethylbenzene (CAS 100-41-4)**										
	Nursery/ elementary school	17	51	μg/m³	1.2	2.2	1.7	6	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ ina.12222.
	Nursery school	1	2	μg/m³	–	6.57	–	–	Czechia	NA	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.
	Elementary school	1	3	μg/m³	0.5	–	–	0.62	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ ijerph10126273.
	Elementary school	1	3	μg/m³	0.53	–	–	1.53	Italy	–	
	Elementary school	1	3	μg/m³	0.16	–	–	0.28	Italy	–	
	Elementary school	1	3	μg/m³	0.19	–	–	0.22	Italy	–	
5	**1,2,3-trimethylbenzene (CAS 526-73-8)**										
	Elementary school	1	3	μg/m³	0.39	–	–	61	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	μg/m³	0.37	–	–	0.86	Italy	–	
	Elementary school	1	3	μg/m³	0.11	–	–	0.18	Italy	–	
	Elementary school	1	3	μg/m³	0.14	–	–	19	Italy	–	

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
6	**m-,p-xylenes (CAS 108-38-3/106-42-3)**										
	Nursery/ elementary school	17	51	μg/m³	1.6	4.4	2.8	14.9	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.
	Nursery school	1	2	μg/m³	–	1.825	–	–	Czechia	NA	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.
	Elementary school	1	3	μg/m³	1.58	–	–	2.01	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	μg/m³	1.66	–	–	5.84	Italy	–	
	Elementary school	1	3	μg/m³	0.48	–	–	0.82	Italy	–	
	Elementary school	1	3	μg/m³	0.56	–	–	0.59	Italy	–	
	School	20	72	μg/m³	1.2	17.7	5	365.2	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
7	**o-xylene (CAS 95-47-6)**										
	Nursery/ elementary school	17	51	µg/m³	< LOD	1.6	0.7	8.9	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.
	Nursery school	1	2	µg/m³	–	9.42	–	–	Czechia	NA	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.
	School	20	72	µg/m³	1.1	3.9	2.3	52.4	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.
8	**Styrene (CAS 100-42-5)**										
	Nursery/ elementary school	17	51	µg/m³	0.9	1.5	1.3	4	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.
	Nursery school	1	2	µg/m³	–	3.325	–	–	Czechia	NA	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
8	**Styrene (CAS 100-42-5)**										
	Elementary school	1	3	µg/m³	0.27	–	–	0.35	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	µg/m³	0.32	–	–	0.59	Italy	–	
	Elementary school	1	3	µg/m³	0.12	–	–	0.24	Italy	–	
	Elementary school	1	3	µg/m³	0.12	–	–	0.14	Italy	–	
	School	20	72	µg/m³	1	1.4	1.2	2.7	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.
9	**Toluene (CAS 108-88-3)**										
	Nursery/elementary school	17	51	µg/m³	1.7	5.2	3.2	24.4	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.
	Nursery school	1	2	µg/m³	–	3.2	–	–	Czechia	NA	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
9	**Toluene (CAS 108-88-3)**										
	Elementary school	1	3	μg/m^3	2.55	–	–	4.84	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	μg/m^3	4.12	–	–	6.81	Italy	–	
	Elementary school	1	3	μg/m^3	0.73	–	–	0.97	Italy	–	
	Elementary school	1	3	μg/m^3	0.83	–	–	0.86	Italy	–	
	School	20	72	μg/m^3	1.8	15.1	6.4	202.5	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.
10	**1,4-dichlorobenzene (CAS 106-46-7)**										
	Nursery/ elementary school	17	51	μg/m^3	< LOD	1.8	< LOQ	9.9	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
10	**1,4-dichlorobenzene (CAS 106-46-7)**										
	Elementary school	1	3	µg/m³	0.01	–	–	0.01	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	µg/m³	0.04	–	–	0.04	Italy	–	
	Elementary school	1	3	µg/m³	0.01	–	–	0.02	Italy	–	
	Elementary school	1	3	µg/m³	0.01	–	–	0.01	Italy	–	
	VOCs – polycyclic aromatic hydrocarbons										
11	**Naphthalene (CAS 91-20-3)**										
	School	114	300	µg/m³	< LOD	2	< LOD	31	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
	Nursery school	2	–	ng/m³	13.1	–	14.8	62.7	Portugal	2015	Oliveira M, Slezakova K, Delerue-Matos C, do Carmo Pereira M, Morais S. Assessment of exposure to polycyclic aromatic hydrocarbons in preschool children: levels and impact of preschool indoor air on excretion of main urinary monohydroxyl metabolites. J Hazard Mater. 2017;322:357–69. doi:10.1016/j.jhazmat.2016.10.004.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
11	**Naphthalene (CAS 91-20-3)**										
	Nursery school	1	2	µg/m³	–	1.16	–	–	Czechia	NA	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.
					VOCs – terpenes						
12	**Limonene (CAS 138-86-3)**										
	Elementary school	1	3	µg/m³	2.51	–	–	4.01	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	µg/m³	2.24	–	–	4.79	Italy	–	
	Elementary school	1	3	µg/m³	4.21	–	–	6.1	Italy	–	
	Elementary school	1	3	µg/m³	1.3	–	–	2.62	Italy	–	
13	**α-pinene (CAS 80-56-8)**										
	Elementary school	1	3	µg/m³	0.92	–	–	1.21	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	µg/m³	0.56	–	–	5.14	Italy	–	
	Elementary school	1	3	µg/m³	1.13	–	–	4.05	Italy	–	
	Elementary school	1	3	µg/m³	0.37	–	–	2.29	Italy	–	

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
13	**α-pinene (CAS 80-56-8)**										
	School	20	72	µg/m³	1	3.4	1.8	32	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.
					VOCs – chlorinated hydrocarbons						
14	**Tetrachloroethylene (CAS 127-18-4)**										
	School	114	300	µg/m³	< LOD	1	< LOD	81	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
	Elementary school	1	3	µg/m³	0.19	–	–	0.19	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ijerph10126273.
	Elementary school	1	3	µg/m³	0.26	–	–	0.31	Italy	–	
	Elementary school	1	3	µg/m³	0.09	–	–	0.13	Italy	–	
	Elementary school	1	3	µg/m³	0.14	–	–	0.15	Italy	–	

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
15	**Trichloroethylene (CAS 79-01-6)**										
	Nursery/ elementary school	17	51	µg/m³	< LOD	2.3	< LOD	28.2	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ ina.12222.
	School	114	300	µg/m³	< LOD	3	< LOD	126	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
						Esters					
16	**Butyl acetate (CAS 123-86-4)**										
	Elementary school	1	3	µg/m³	0.85	–	–	1.08	Italy	–	de Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int J Environ Res Public Health. 2013;10:6273–91. doi:10.3390/ ijerph10126273.
	Elementary school	1	3	µg/m³	0.48	–	–	0.7	Italy	–	
	Elementary school	1	3	µg/m³	0.19	–	–	0.29	Italy	–	
	Elementary school	1	3	µg/m³	0.19	–	–	1.01	Italy	–	
	Nursery school	1	2	µg/m³	–	9.315	–	–	Czechia	NA	Senitkova IJ. Occurrence of indoor VOCs in nursery school – case study. IOP Conference Series: Materials Science and Engineering. 2017;245:082027. doi:10.1088/1757-899X/245/8/082027.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
Semi-volatile organic compounds (SVOCs)											
17	**Benzo[a]pyrene (CAS 50-32-8)**										
	School	35	35	pg/m³	23	105	96	425	Spain	2012/2013	Mortamais M, Pujol J, van Drooge BL, Macià D, Martínez-Vilavella G, Reynes et al. Effect of exposure to polycyclic aromatic hydrocarbons on basal ganglia and attention-deficit hyperactivity disorder symptoms in primary school children. Environ Int. 2017;105:12–19. doi:10.1016/j.envint.2017.04.011.
	Nursery school	2	–	ng/m³	0.0501	–	0.0754	0.109	Portugal	2015	Oliveira M, Slezakova K, Delerue-Matos C, do Carmo Pereira M, Morais S. Assessment of exposure to polycyclic aromatic hydrocarbons in preschool children: levels and impact of preschool indoor air on excretion of main urinary monohydroxyl metabolites. J Hazard Mater. 2017;322:357–69. doi:10.1016/j.jhazmat.2016.10.004.
	School	39	–	ng/m³	–	–	0.1	–	Spain	2012/2013	Pacitto A, Stabile L, Viana M, Scungio M, Reche C, Querol X et al. Particle-related exposure, dose and lung cancer risk of primary school children in two European countries. Sci Total Environ. 2018;616–17;720–9. doi:10.1016/j.scitotenv.2017.10.256.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
18	**Phenanthrene (CAS 85-01-8)**										
	Nursery/ elementary school	30	62	ng/m^3	1.6	–	8.7	> 50	France	2017	Raffy G, Mercier F, Blanchard O, Derbez M, Dassonville C, Bonvallot N et al. Semi-volatile organic compounds in the air and dust of 30 French schools: a pilot study. Indoor Air. 2017;27:114–27. doi:10.1111/ina.12288.
	Nursery school	2	–	ng/m^3	6.1	–	22	56.1	Portugal	2017	Oliveira M, Slezakova K, Delerue-Matos C, do Carmo Pereira M, Morais S. Assessment of exposure to polycyclic aromatic hydrocarbons in preschool children: levels and impact of preschool indoor air on excretion of main urinary monohydroxyl metabolites. J Hazard Mater. 2017;322:357–69. doi:10.1016/j.jhazmat.2016.10.004.
						Phthalates					
19	**Diethyl phthalate (CAS 84-66-2)**										
	Nursery/ elementary school	30	53	ng/m^3	40	–	221	684	France	2010	Raffy G, Mercier F, Blanchard O, Derbez M, Dassonville C, Bonvallot N et al. Semi-volatile organic compounds in the air and dust of 30 French schools: a pilot study. Indoor Air. 2017;27:114–27. doi:10.1111/ina.12288.
	Day-care centre	63	63	µg/m^3	0.095	0.516	0.468	2.613	Germany	2011/2012	Fromme H, Lahrz T, Kraft M, Fembacher L, Dietrich S, Sievering S et al. Phthalates in German day-care centers: occurrence in air and dust and the excretion of their metabolites by children (LUPE 3). Environ Int. 2013;61:64–72. doi:10.1016/j.envint.2013.09.006.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
20	**Diisobutyl phthalate (CAS 84-69-5)**										
	Nursery/ elementary school	30	62	ng/m³	207	–	> 800	> 800	France	2010	Raffy G, Mercier F, Blanchard O, Derbez M, Dassonville C, Bonvallot N et al. Semi-volatile organic compounds in the air and dust of 30 French schools: a pilot study. Indoor Air. 2017;27:114–27. doi:10.1111/ina.12288.
	Day-care centre	63	63	µg/m³	0.095	0.516	0.468	2.613	Germany	2011/2012	Fromme H, Lahrz T, Kraft M, Fembacher L, Dietrich S, Sievering S et al. Phthalates in German day-care centers: occurrence in air and dust and the excretion of their metabolites by children (LUPE 3). Environ Int. 2013;61:64–72. doi:10.1016/j.envint.2013.09.006.
21	**Di-n-butyl phthalate (CAS 84-74-2)**										
	Nursery/ elementary school	30	62	ng/m³	37	–	228	> 800	France	2010	Raffy G, Mercier F, Blanchard O, Derbez M, Dassonville C, Bonvallot N et al. Semi-volatile organic compounds in the air and dust of 30 French schools: a pilot study. Indoor Air. 2017;27:114–27. doi:10.1111/ina.12288.
	Day-care centre	63	63	µg/m³	0.049	0.283	0.227	1.276	Germany	2011/2012	Fromme H, Lahrz T, Kraft M, Fembacher L, Dietrich S, Sievering S et al. Phthalates in German day-care centers: occurrence in air and dust and the excretion of their metabolites by children (LUPE 3). Environ Int. 2013;61:64–72. doi:10.1016/j.envint.2013.09.006.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
						Brominated flame retardants					
22	**Brominated diphenyl ether 47 (CAS 5436-43-1)**										
	School	2	–	pg/m³	–	–	131	459	Norway	2017	Malliari E, Kalantzi O-I. Children's exposure to brominated flame retardants in indoor environments – a review. Environ Int. 2017;108:146–69. doi:10.1016/j.envint.2017.08.011.
	School	2	3	µg/m³	–	–	0.000131	–	Norway	2016	Cequier E, Ionas AC, Covaci A, Marcé RM, Becher G, Thomsen C. Occurrence of a broad range of legacy and emerging flame retardants in indoor environments in Norway. Environ Sci Technol. 2014;48(12):6827–35. doi:10.1021/es500516u.
						Musks					
23	**Galaxolide (CAS 1222-05-5)**										
	Nursery/ elementary school	30	62	ng/m³	14	–	> 50	> 50	France	2010	Raffy G, Mercier F, Blanchard O, Derbez M, Dassonville C, Bonvallot N et al. Semi-volatile organic compounds in the air and dust of 30 French schools: a pilot study. Indoor Air. 2017;27:114–27. doi:10.1111/ina.12288.
24	**Tonalide (CAS 21145-77-7)**										
	Nursery/ elementary school	30	90	ng/m³	3.5	–	20	> 50	France	2010	Raffy G, Mercier F, Blanchard O, Derbez M, Dassonville C, Bonvallot N et al. Semi-volatile organic compounds in the air and dust of 30 French schools: a pilot study. Indoor Air. 2017;27:114–27. doi:10.1111/ina.12288.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
						Inorganic compounds					
25	**Nitrogen dioxide (CAS 10102-44-0)**										
	School	NA	NA	μg/m³	8.66	44.26	–	230	NA	NA	Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S & on behalf of the SINPHONIE Group. Indoor air quality and sources in schools and related health effects. J Toxicol Environ Health B Crit Rev. 2013;16:8:491–550. doi:10.1080/10937404.2013.853609.
	School	NA	NA	μg/m³	6.6	32.96	–	170	NA	NA	
	School	NA	NA	μg/m³	13.9	59.52	–	250	NA	NA	
	School	NA	NA	μg/m³	13	29	–	47	NA	NA	
	School	NA	NA	μg/m³	12.5	–	–	37	NA	NA	
	School	NA	NA	μg/m³	15.2	–	–	33.2	NA	NA	
	School	114	300	μg/m³	< LOD	14	11	88	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
26	**Carbon monoxide (CAS 630-08-0)**										
	School	NA	NA	mg/m³	–	0.67	–	–	Portugal	2013	Oliveira M, Slezakova K, Delerue-Matos C, do Carmo Pereira M, Morais S. Indoor air quality in preschools (3- to 5-year-old children) in the northeast of Portugal during spring–summer season: pollutants and comfort parameters. J Toxicol Environ Health A. 2017;80(13–15):740–55. doi:10.1080/15287394.2017.1286932.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
26	**Carbon monoxide (CAS 630-08-0)**										
	School	114	300	Parts per million (ppm)	< LOD	1	< LOD	122	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
	School	20	72	mg/m^3	0.01	0.48	0.38	1.7	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.
27	**Ozone (CAS 10028-15-6)**										
	Nursery school	2	1 playroom 1 classroom	mg/m^3	0.02	0.08	–	–	Portugal	2013	Oliveira M, Slezakova K, Delerue-Matos C, do Carmo Pereira M, Morais S. Indoor air quality in preschools (3- to 5-year-old children) in the northeast of Portugal during spring–summer season: pollutants and comfort parameters. J Toxicol Environ Health A. 2017;80(13–15):740–55. doi:10.1080/15287394.2017.1286932.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
27	**Ozone (CAS 10028-15-6)**										
	School	114	300	μg/m³	< LOD	8	3	142	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.
					Particulate matter (PM)						
28	**PM with diameter of less than 10 μm (PM_{10})**										
	School	NA	NA	μg/m³	69	148	141	247	Italy	2010	Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S & on behalf of the SINPHONIE Group. Indoor air quality and sources in schools and related health effects. J Toxicol Environ Health B Crit Rev. 2013;16:8:491–550. doi:10.1080/10937404.2013.853609.
	School	NA	NA	μg/m³	92	158	154	260	Italy	2010	
	School	NA	NA	μg/m³	17	54	43	131	Norway	2010	
	School	NA	NA	μg/m³	14	33	32	53	Sweden	2010	
	School	NA	NA	μg/m³	112	169	160	233	Denmark	2010	
	School	NA	NA	μg/m³	86	112	106	151	France	2010	
	School	NA	NA	μg/m³	69	148	141	247	Italy	2010	
	School	NA	NA	μg/m³	9	79.3	70	300	NA	NA	
	School	1	5	μg/m³	32.5	287.84	–	2061.2	Slovakia	2013/2014	Vilcekova S, Meciarova L, Kridlova Burdova E, Katunska J, Kosicanova D, Doroudiani S. Indoor environmental quality of classrooms and occupants' comfort in a special education school in Slovak Republic. Build Environ. 2017;120:29–40. doi:10.1016/j.buildenv.2017.05.001.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
28	PM with diameter of less than 10 µm (PM_{10})										
	School	10	44	µg/m³	32	82.24	70	197	Serbia	NA	Matic B, Rakic U, Jovanovic V, Dejanovic S, Djonovic N. Key factors determining indoor air PM10 concentrations in naturally ventilated primary schools in Belgrade, Serbia. Zdr Varst. 2017;56(4):227–35. doi:10.1515/sjph-2017-0031.
	School	39	–	µg/m³	–	–	60.7	–	Spain	2012/2013	Pacitto A, Stabile L, Viana M, Scungio M, Reche C, Querol X et al. Particle-related exposure, dose and lung cancer risk of primary school children in two European countries. Sci Total Environ. 2018;616–17;720–9. doi:10.1016/j.scitotenv.2017.10.256.
	Day-care centre	30	–	µg/m³	–	75.91	–	–	NA	NA	Morawska L, Ayoko GA, Bae GN, Buonanno G, Chao CYH, Clifford S et al. Airborne particles in indoor environment of homes, schools, offices and aged care facilities: the main routes of exposure. Environ Int. 2017;108:75–83. doi:10.1016/j.envint.2017.07.025.
	School	78	–	µg/m³	–	116.92	–	–	NA	NA	
	School	281	–	µg/m³	–	182.03	–	–	NA	NA	
	Nursery school	2	24	µg/m³	–	122.11	–	–	Poland	2013/2014	Mainka A, Zajusz-Zubek E. Indoor air quality in urban and rural preschools in Upper Silesia, Poland: particulate matter and carbon dioxide. Int J Environ Res Public Health. 2015;12:7697–711. doi:10.3390/ijerph120707697.
	Nursery school	2	24	µg/m³	–	103.89	–	–	Poland	2013/2014	

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
28	**PM with diameter of less than 10 µm (PM_{10})**										
	School	20	72	µg/m³	56	139	127	320	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.
29	**PM with diameter of less than 2.5 µm ($PM_{2.5}$)**										
	School	NA	NA	µg/m³	1.6	–	–	13.7	NA	NA	Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S & on behalf of the SINPHONIE Group. Indoor air quality and sources in schools and related health effects. J Toxicol Environ Health B Crit Rev. 2013;16:8:491–550. doi:10.1080/10937404.2013.853609.
	School	NA	NA	µg/m³	8	–	–	28	NA	NA	
	Nursery school	2	1 playroom 1 classroom	µg/m³	7.58	17.5	–	28.1	Portugal	2013	Oliveira M, Slezakova K, Delerue-Matos C, do Carmo Pereira M, Morais S. Indoor air quality in preschools (3- to 5-year-old children) in the northeast of Portugal during spring–summer season: pollutants and comfort parameters. J Toxicol Environ Health A. 2017;80(13–15):740–55. doi:10.1080/15287394.2017.1286932.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
29	**PM with diameter of less than 2.5 µm ($PM_{2.5}$)**										
	School	1	5	µg/m³	5.1	17.12	–	50.1	Slovakia	2013/2014	Vilcekova S, Meciarova L, Kridlova Burdova E, Katunska J, Kosicanova D, Doroudiani S. Indoor environmental quality of classrooms and occupants' comfort in a special education school in Slovak Republic. Build Environ. 2017;120:29–40. doi:10.1016/j.buildenv.2017.05.001.
	Nursery/ elementary school	17	51	µg/m³	–	22	–	–	France	2010	Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016;26:350–65. doi:10.1111/ina.12222.
	Day-care centre	304	–	µg/m³	–	44.27	–	–	NA	NA	Morawska L, Ayoko GA, Bae GN, Buonanno G, Chao CYH, Clifford S et al. Airborne particles in indoor environment of homes, schools, offices and aged care facilities: the main routes of exposure. Environ Int. 2017;108:75–83. doi:10.1016/j.envint.2017.07.025.
	School	18	–	µg/m³	–	40.47	–	–	NA	NA	
	Day-care centre	63	–	µg/m³	–	52.31	–	–	NA	NA	
	School	159	–	µg/m³	–	50.14	–	–	NA	NA	
	School	114	300	µg/m³	4	44	37	250	Europe	2011/2012	European Commission Directorate General for Health and Consumers, Directorate General Joint Research Centre. Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE). Final report. Luxembourg: Publications Office of the European Union; 2014. doi:10.2788/99220.

Table A1 cont.

No.	Type of building	Number of buildings	Number of rooms	Unit	Minimum	Arithmetic mean	Median	Maximum	Location	Sampling year	Reference
29	**PM with diameter of less than 2.5 µm ($PM_{2.5}$)**										
	Nursery school	2	24	µg/m^3	–	94.08	–	–	Poland	2013/2014	Mainka A, Zajusz-Zubek E. Indoor air quality in urban and rural preschools in Upper Silesia, Poland: particulate matter and carbon dioxide. Int J Environ Res Public Health. 2015;12:7697–711. doi:10.3390/ijerph120707697.
	Nursery school	2	24	µg/m^3	–	66.72	–	–	Poland	2013/2014	
	School	20	72	µg/m^3	39	94	82	244	Portugal	2011/2013	Madureira J, Paciencia I, Rufo J, Severo M, Ramos E, Barros H et al. Source apportionment of CO_2, PM_{10} and VOC levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal. Build Environ. 2016;96:198–205. doi:10.1016/j.buildenv.2015.11.031.

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The World Health Organization (WHO) is a specialized agency of the United Nations creted in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

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