European Commission

SINPHONIE

Schools Indoor Pollution & Health Observatory Network in Europe

Final Report

sinphonie
Schools Indoor Pollution and Health: Observatory Network in Europe

REGIONAL ENVIRONMENTAL CENTER

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Abstract
This document is the final report of the SINPHONIE (Schools Indoor Pollution and Health: Observatory Network in Europe) project. SINPHONIE was funded by the European Parliament and carried out under a contract with the European Commission's Directorate-General for Health and Consumers (DG SANCO) (SANCO/2009/C4/04, contract SI2.570742). The SINPHONIE project established a scientific/technical network to act at the EU level with the long-term perspective of improving air quality in schools and kindergartens, thereby reducing the risk and burden of respiratory diseases among children and teachers potentially due to outdoor and indoor air pollution. At the same time, the project supports future policy actions by formulating guidelines, recommendations and risk management options for better air quality and associated health effects in schools.

SINPHONIE
Schools Indoor Pollution and Health
Observatory Network in Europe

Final Report

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This report presents the work performed by a consortium of 38 partners from 25 countries that involved around 300 people of specialised scientific and/or technical background.

The co-authors of this report wish to express their deep gratitude to all of their collaborators for their outstanding contribution to the execution of the SINPHONIE project. Names of all contributors can be found at the end of this report as well as on the SINPHONIE project's website (www.sinphonie.rec.org).

Special recognition goes to the teachers, pupils and parents who participated in the SINPHONIE project, for their enthusiasm and close cooperation.

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1 Introduction

The quality of the indoor environment is a major health concern due to the fact that most of the indoor air is merely outdoor (or ambient) air with additional pollutants emitted from building materials and consumer products. The indoor environment forms the basic breathing and dermal exposure background for 90% of the lifetime of the European population. The quality of the ambient air in most cities falls far short of the World Health Organization (WHO) guidelines, and most of the indoor air interacts directly with the ambient air through openings that can be controlled to some extent (windows, doors and air-specific uptakes and exhausts) as well as some unwanted openings (leaks, cracks, etc.). The outdoor air is therefore one of the major sources of pollution indoors [56]. To address this problem, the use of mechanical systems equipped with filtering and, more rarely, cleaning capabilities, has been presented as a panacea to reduce both outdoor and indoor air pollution. However, such means are not necessary if local authorities can develop policies and measures on clean ambient air in general, and specifically in schools surroundings. Appropriate rules can be adopted regarding the location, design and management of school buildings, taking into account geographical and current climatic specificities and future climate change scenarios.

The SINPHONIE project aimed to gather new, more and better indoor air quality (IAQ) and associated health data from schools across as many European countries as possible. The ultimate goal was to compile a number of recommendations to inform existing and future policies and to propose a set of guidelines towards a healthy school environment in Europe. This approach was linked to the European Environment and Health Action Plan 2004-2010 [29] and the Environment and Health Strategy of the EU.

The SINPHONIE project built on the outcomes of previous IAQ projects, as summarised below. Most of these projects had a broad, multidisciplinary approach related to IAQ and health, and some of them had a specific focus on IAQ and children's health in schools and kindergartens.

The EU-funded EnVIE project [33, 34] proposed a two-step strategy for the management of IAQ - source control and ventilation - as part of an overall strategy of interventions linked to building location, design, construction, operation, management and maintenance. The EnVIE concept makes it possible to avoid using the high airflow rates that would otherwise be required to lower the indoor air pollution load in buildings below the WHO guideline values [4]. In terms of IAQ-related policies and strategies, EnVIE recommended the coordinated alignment and implementation of relevant policy and standardisation instruments, such as the former Construction Products Directive (89/106/EEC) [32], REACH (EC 1907/2006) [87], EPBD (2010/31/EU) [25], GPSD (2001/95/EC) [40], etc., as the only efficient way to tackle potential sources of indoor pollutants and related indoor air exposure. EnVIE also triggered the development of harmonisation frameworks for labelling emissions from construction materials and products, and for monitoring, auditing and reporting the status of IAQ in EU buildings, including school buildings. Buildings such as offices, schools and homes differ so greatly in terms of scope, requisites and use that it makes sense to refer to schools as a special case in the context of IAQ policies. Special attention needs to be taken due to the fact that children are a particularly susceptible part of the population [17]. In Europe, there are over 64 million students and almost 4.5 million teachers who spend many hours per day inside kindergartens, primary and secondary schools. Children spend more time in schools than in any other place except home.

In 2000, the European Federation of Allergies (EFA) and the Airways Diseases Patients Association implemented the EU-funded project Indoor Air Pollution in Schools. The project found evidence that the right to breathe clean air in schools was not widely recognised in Europe, and that there was a need for further research to evaluate the impact of air pollutants in schools on children's well-being, health and performance and to provide a sound basis for promoting European regulations and campaigns directed at a better school environment [12, 38].

Between 2004 and 2005, the EU-funded pilot study Health Effects of the School Environment (HESE) provided data on indoor air pollutants and health effects in schools in five European countries (Siena and Udine, Italy; Reims, France; Oslo, Norway; Uppsala, Sweden; Aarhus, Denmark) [43]. Twenty-one schools (46 classrooms) were evaluated and respiratory/allergic health information was collected for more than 600 children. The HESE study promoted awareness of the importance of good air quality for children's respiratory health and provided practical tools for its evaluation, improvement and maintenance. For the first time, the HESE study provided data from a wide range of locations from heterogeneous countries using the same standardised procedure. It showed the feasibility of multi-centre studies to monitor school IAQ and health and represented an important basis for further research. Outdoor/indoor monitoring included comfort data (e.g. temperature, relative humidity), ventilation, lighting, particulate matter (PM), nitrogen dioxide (NO_2), carbon dioxide (CO_2), ozone (O_3), formaldehyde, dust and air allergens, moulds and bacteria [17]. The HESE study revealed a number of typical IAQ problems in schools, particularly due to poor ventilation, and a widespread lack of awareness and preparedness to cope with environmental problems and take care of more vulnerable children, such as those suffering from asthma. HESE has also identified health impacts among children exposed to higher levels of indoor pollution at school, in the form of respiratory disturbances and reduced nasal patency [98].

Between 2003 and 2008, the pilot project AIRMEX [31] investigated exposure to chemicals in the indoor air and possible health risks associated mainly with volatile organic compounds (VOCs). The project was funded and coordinated by the EC's Joint Research Centre (JRC) and included schools, kindergartens and other types of public buildings in cities in selected EU member states. The key findings highlighted the need for further research to address the burden of indoor air pollution on public health in the EU, in particular in indoor environments where children spend most of their time, such as schools and kindergartens.

Other projects addressing IAQ in schools have been carried out at national level (e.g. the BiBa project in Belgium (https://esites.vito.be/sites/BIBA/EN/home/Pages/home.aspx); the OQAI (Observatory Network on Indoor Air Quality) in France (http://www.air-interieur.org/); and the SaudAR project in Portugal [131], which have highlighted that the state of school buildings and inappropriate ventilation levels are major contributors to poor IAQ and negative health effects in schools.

The SEARCH project (School Environment and Respiratory Health of Children) (2006–2009) [20] was an opportunity for new cooperation on school related air quality matters between eight countries: Albania, Austria, Bosnia and Herzegovina, Hungary, Italy, Norway, Serbia and Slovakia. The project was funded by the Italian Ministry for the Environment, Land and Sea and coordinated by the Regional Environmental Centre in Hungary. Ten schools from each country were involved, with the number of classrooms ranging from 35 to 40, except for Italy, where there were 13 schools and 55 classrooms. The main objectives of the SEARCH project were to assess the association between the school environment and children's respiratory health, and to draft recommendations for improving air quality in the school environment. Outdoor/indoor monitoring and assessment included atmospheric data (e.g. temperature, relative humidity), carbon monoxide (CO), CO_2, NO_2, benzene, toluene, xylenes, formaldehyde and particulate matter with aerodynamic diameter smaller than 10 µm ($PM_{10)}$ [20, 109].

Other studies have confirmed the links between poor air quality in schools and children's health in both European (mainly northern European) and non-European countries, including a study undertaken in Shanghai involving 10 schools (30 classrooms) and about 1,400 schoolchildren [3, 77]; and another involving 10 schools and about 2,000 pupils in the city of Taiyuan, China [127]. Another large-scale study in 11 schools (87 classrooms) in the USA [16] also pointed out the implications of the school environment for the health of children.

The SINPHONIE project was based on the outcomes of these earlier projects and at the same time created synergies with concurrent projects run by the European Commission (PILOT INDOOR AIR MONIT [129]) and WHO (pilot project on IAQ in schools) [132].

2 Motivation and Objectives

Based on the Eurostat demographic database [6], during the 2010/2011 academic year there were slightly more than 64 million students in the EU in kindergartens, primary and lower secondary education. There were about 15 million children in nursery schools, about 28 million pupils in primary schools, and about 22 million students in lower secondary schools. In most countries, students attend school for five or six days per week and spend on average from 700 to 900 hours per year in classrooms. The number of teachers working in primary and secondary schools is close to 4.5 million. The teaching profession constitutes 3% of the total working population in the EU.

Children breathe a greater volume of air relative to their body weight compared to adults, which means that they are at particular risk from IAQ-related problems. In addition, many children are used to breathing through their mouths, bypassing the natural defences of the nasal passages. Since attendance within the school environment is compulsory, the school authorities should be under an obligation to provide a school environment that is appropriate for children, in particular to those with allergies or other kind of hypersensitivity. For these reasons, it is important to thoroughly investigate the links between air quality in schools and the health of children.

Indoor air quality and its associated impacts on health, as well as the effectiveness of remedial measures [30], have been far less studied than in some other types of buildings (e.g. offices).

The few studies carried out on the effectiveness of remedial measures in Europe show that schools frequently have IAQ problems because of poor building construction and maintenance, poor cleaning and poor ventilation. The studies also demonstrate that pollution at school is complex and variable and has clear impacts on health. Various air pollutants (physical, chemical, microbiological) can be found in classrooms, sometimes in quite high concentrations. An overview of the main indoor pollutants in schools and related sources can be found in EFA [30] and E. Csobod et al. [20].

Air quality in schools can have an impact on children's health, attendance and learning performance [7, 11, 38]. Respiratory health in schools is particularly affected by air pollutants that enter the body through the inhalation route, with allergic subjects being at higher risk. Indoor air quality in schools may be responsible for acute health effects (e.g. respiratory irritation), chronic effects (e.g. asthma and allergies), symptoms associated with sick building syndrome (SBS) (headaches, nausea etc.), and lack of concentration [82]. Symptoms commonly attributed to poor IAQ include: headaches; fatigue; shortness of breath; sinus congestion; coughing; sneezing; eye, nose and throat irritation; skin irritation; dizziness; and nausea. Odours are often associated with a perception of poor air quality, whether or not they cause health-related symptoms.

Some studies have observed a reduction in school performance and increased absenteeism as a result of exposure to poor air quality in schools [42, 74, 101].

Knowledge of indoor air exposure levels and their sources in various types of buildings (dwellings, offices, schools, etc.) across European countries is important, as it provides an overall picture of the major sources and causes responsible for IAQ-related health problems. However, the complexity and specificity of the school environment across Europe, taking into account the huge number and variety of pollution sources and the differences in occupants' behaviour, operational and maintenance practices and climatic conditions, make it very difficult to identify IAQ-related health problems in schools. Furthermore, in most cases the existing datasets are not comparable, as they were not produced according to harmonised and standardised procedures and protocols.

The path from obtaining exposure data to investigating associated health implications and formulating recommendations is long and generally arduous. However, an understanding of children's exposure to particular indoor air pollutants and sources is a prerequisite for the formulation of policy recommendations and management options. A research plan of this nature involves various steps: the monitoring of the indoor environment; the toxicological assessment of physical, chemical and biological hazards; the monitoring of health effects related to IAQ; and the completion of health risk assessment. The risk assessment process is crucial and involves the identification and quantification of factors that have an impact on the health and well-being of building occupants. The outcome of the risk assessment may suggest the need for risk management actions by controlling, mitigating and/or remediating the status of IAQ in school environment.

In the SINPHONIE project, a coherent understanding of the effects of indoor air exposure in schools on the health of schoolchildren was obtained by the use of a standardised procedure and protocols that were developed taking into account potential confounders.

With its special focus on primary schools and kindergartens, SINPHONIE aimed to capitalise on, and take advantage of, the opportunity to extend existing knowledge and information, mainly obtained in Western European countries, by covering new member states and some accession countries. It offered an integrated and standardised methodology for performing IAQ-related exposure and risk assessment in European schools and produced a set of recommendations, guidelines and good practices that can help to ensure a healthy indoor environment for children in schools within the EU. This project involved advanced research on health, environment, transport and climate change for the improvement of air quality in schools and kindergartens.

The ultimate objective of SINPHONIE was to produce recommendations and guidelines on remedial measures in the school environment to cover a wider array of situations in Europe and to disseminate these guidelines to stakeholders able to take action. To enable the accomplishment of this ultimate objective, the required technical objectives of SINPHONIE were to:

- review critically and collate European (and non-European) research on the health effects most relevant to indoor air exposure in schools; assess the policy relevance of the objectives and conclusions of this research; and identify the epidemiological and toxicological research required for knowledge-based policy development;
- assess building characteristics and patterns of everyday use in the selected classrooms that influence their IAQ;

- measure physical and comfort parameters (temperature, relative humidity and ventilation rate) and chemical and biological pollutants in the indoor (and related outdoor) air in schools and childcare settings throughout Europe in order to produce new exposure data for an array of pollutants: formaldehyde, benzene, α-pinene and limonene, naphthalene, NO_2, CO, CO_2, radon, trichloroethylene, tetrachloroethylene, polycyclic aromatic hydrocarbons (PAH) and benzo(α)pyrene (BaP), particulate matter (PM_{10} and $PM_{2.5}$), allergens in dust and mould, and bacteria in dust and air;
- evaluate the impact of the outdoor environment on IAQ in schools, including transportation, traffic and the effects of climate change;
- assess the influence of building characteristics, cleaning products and ventilation systems on the exposure data obtained;
- assess the impacts of outdoor air pollution abatement measures, including measures taken in the short-term, on IAQ in schools and on children's exposure in school environment;
- make a systematic source apportionment of indoor air pollutants in school environments in quantitative terms;
- assess the influence of mixtures of pollutants in the indoor air and the emergence of new pollutants caused by chemical and biochemical interactions;
- obtain data on the health status of children using questionnaire surveys, and also via clinical tests, focusing on asthma, respiratory infections, upper respiratory tract symptoms, coughing, wheezing, dyspnea, allergic rhinitis, bronchitis and school performance;
- evaluate the impact of the indoor air in classrooms on children's health and performance in order to define priorities for policy development;
- evaluate the effectiveness of appropriate ventilation to reduce ambient air pollution in schools;
- produce recommendations and guidelines on remedial measures related to the school environment to cover a wider array of situations in Europe; and
- disseminate the SINPHONIE outputs and recommendations to stakeholders able to undertake actions on the issues highlighted by the project.

3 Methods

3.1 SINPHONIE research design

In order to fulfil the SINPHONIE project's technical objectives, a two-year multidisciplinary study was designed and undertaken, with EU-wide geographical coverage and comprising work supported by a diversified set of environment and health field studies in the school environment, data analysis, health risk assessment, and finally the elaboration of recommendations and guidelines for healthy school environments in Europe. The tasks within SINPHONIE were performed through eight work packages (WPs) - the seven shown in Figure 1 plus two others: Management/Coordination (WP1) and Communication and Dissemination (WP8) (see annex 1).

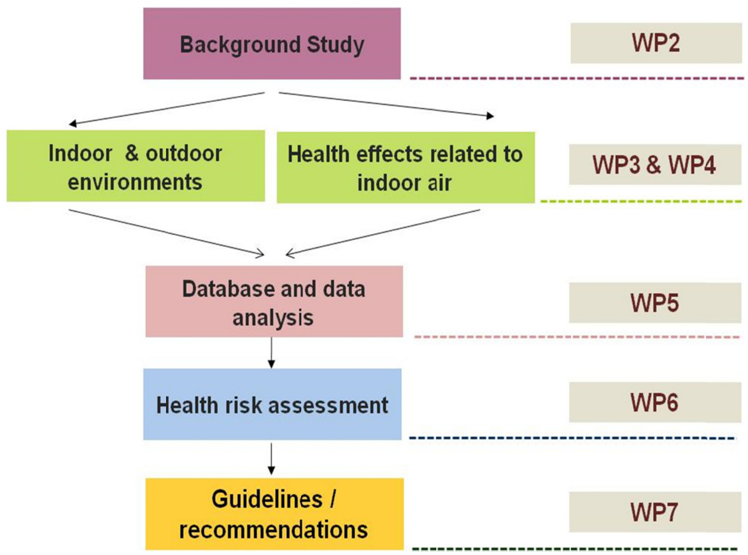


Figure 1. SINPHONIE research design structure

Standardised procedures and protocols for monitoring indoor and ambient air quality and clinical tests for identifying associated health effects were first developed within WP3 and WP4, respectively. These were presented and explained to the scientific and technical staff involved in SINPHONIE in dedicated environmental health training sessions (which included quality assurance requirements) organised by the European Commission's Joint Research Centre (JRC) before the field activities in the selected schools.

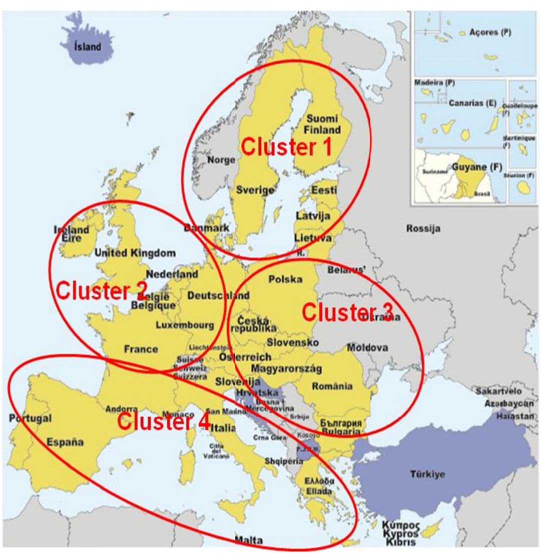
Laboratories and partners with significantly different levels of experience in relation to IAQ-related monitoring and assessment were involved in the chemical, physical and biological assessments, as well as in the management of the questionnaires. Common methodologies, coordinated by the Regional Environmental Centre for Central and Eastern Europe (REC), the National Institute for Health and Welfare, Finland (THL) and the National Institute of Environmental Health, Hungary (NIEH), and centralised laboratories were the preferred choice for the analysis of biological contaminants, due to the limited availability of laboratories for biological agents across the European region. In addition, recent developments in microbial exposure assessment were carefully considered, meaning that not only viable, but also non-viable, microbial compounds were measured and analyses were carried out on long-term integrated dust samples rather than short-term air samples, since such dust samples are less prone to the short-term fluctuations in microbial levels typically observed in air samples. This ensured the creation of a unique, extensive and highly comparable dataset of biological contaminants in schools across Europe, which can establish the groundwork and serve as a reference for future assessments.

3.2 The geographical clusters in SINPHONIE

Participating countries were grouped into four geographical clusters on the basis of climatic conditions (i.e. mean temperatures in the heating season). Based on the four clusters, an inventory of existing school-related IAQ field studies was made at country level. This information made possible to estimate the number of IAQ field studies that should be organised in each country. The selection of countries was in accordance with the call for tenders launched by DG SANCO (EU member states and countries outside the EU in Central and Eastern Europe).

Table 1 presents the number of schools that participated in the field studies per cluster.

Table 1. Schools participating in the field studies per cluster (N=114 schools)

	Countries included	Participating schools, N (%)
	Cluster 1. Northern Europe [a)] Sweden, Finland, Estonia, Lithuania	13 (11)
	Cluster 2. Western Europe [b)] Belgium, UK, France, Austria, Germany	26 (23)
	Cluster 3. Central-Eastern Europe [c)] Poland, Slovakia, Czech Republic, Hungary, Romania, Bulgaria, Serbia, Bosnia and Herzegovina	44 (39)
	Cluster 4. Southern Europe [d)] Italy, Portugal, Malta, Greece, Cyprus, Albania	31 (27)

a) Cold climate (cold winters), large differences between old and new buildings, well-insulated rooms, mechanical ventilation systems.
b) Moderate climate (moderately cold winters), differences between old and new buildings (ventilation, insulation, passive and low-energy construction).
c) Colder climate (cold winters), moderate to low insulation, no ventilation systems.
d) Warm (warmer winters), Mediterranean climate, moderate to low insulation, natural ventilation.

The field studies were organised in schools in 23 European countries that had all participated in the field monitoring. Each participating country contributed data from three to six schools to the main SINPHONIE study.

3.3 Selection of schools and classrooms

Priority was given to acquiring knowledge about the schools in terms of their geographical location, climate conditions and ventilation practices/systems (natural or mechanical ventilation). Pre-defined issues were the influence of location and the influence of ventilation. With respect to location, the parameters of interest were the influence of the surroundings (urban/rural, green zone/heavy traffic/industry, interior/maritime, north/south/east/west) and climatic conditions. Concerning ventilation it was important to investigate the influence of the type of ventilation: natural, mechanical (with and without treatment of air), or a mixture of both.

SINPHONIE partners were requested to choose schools that were representative of the building stock in their country in terms of typology, construction techniques and age. However, in the case of ventilation, partners were asked to include examples of the two main ventilation types (natural and mechanical) if applicable. In Central-Eastern Europe, where natural ventilation is most common, schools featuring natural ventilation were selected. One of the SINPHONIE case studies focused mainly on ventilation and IAQ provided additional information about the effects of different types of ventilation.

According to the call for tenders' text, SINPHONIE was to focus on classrooms in primary schools and kindergartens. The same selection criteria were applied to these environments and classrooms, age being the only criterion not applicable to classrooms in kindergartens.

3.3.1 School selection criteria

Taking into account the above criteria, and bearing in mind that each country was to study from three to six schools, it was suggested that preference should be given to public schools, with an attempt to respect the following proportion:

- two or three schools located in a rural or green area; and
- two or three schools located in an urban area (near a strong source of air pollution such as heavy traffic or industry).

Where the above conditions were not feasible, schools located in places with as much of a contrast in environmental conditions as possible were to be chosen.

3.3.2 Classroom selection criteria

One highly important aspect of the project was the approval and support of school teachers and managers for the planned SINPHONIE field studies. Priority was given to selecting schools with motivated school managers, teachers and pupils.

In each school, three classrooms were selected according to the following criteria: classrooms used by children aged between eight and eleven[1]; classrooms representative of the school; classrooms occupied by the same class of pupils for the whole school year, if possible with full occupation per weekday; classrooms located on different floor levels, if applicable; classrooms located in places within the building with as much contrast as possible, taking into consideration aspects such as indoor and outdoor sources affecting IAQ, and orientation (facing the street or the yard); and classrooms in use for at least the last six months, in order to avoid encountering emissions from new building materials.

In the case of classrooms with equivalent conditions, those with a higher number of pupils were chosen.

3.4 Building conditions and their outdoor context: building checklist

3.4.1 Building checklist and modelling simulations

The indoor environment of a school building is a complex system involving many parameters that may have an impact on health and comfort. A school building is a physical construction, used, among other purposes, to regulate or control environmental exposures. Several spaces may be defined within a school building that are used for different purposes (e.g. classrooms, dining halls, science workshops/labs, gyms, locker rooms, outside environment) and that have different requirements according to occupation density, type of ventilation (e.g. mechanical ventilation on/off, natural ventilation etc.) and pollution load.

The school building itself, like any other building, through its design and given the appropriate criteria and requirements for each specific application and the materials to be employed, is clearly the primary "system" to be optimised from the IAQ perspective. The quality of the indoor air depends strongly, on the one hand, on the interaction between the building and its outdoor environment, and, on the other hand, on the way the building is used, including the behaviour of its occupants. Air-conditioning systems, when strictly a technical necessity, represent a complement to the building itself in order to guarantee the desired conditions in each specific space.

Air pollutants in buildings are linked to various indoor factors (e.g. building structure, surfaces, furnishing, ventilation systems, etc.), the specific activities of the occupants, and the presence of nearby outdoor sources. Thus in order to be able to understand the environmental context of the SINPHONIE schools, it was very important to obtain information about the characteristics of the school buildings, including outdoor pollution sources, and also to integrate information on the behaviour of building occupants (activities in classrooms, cleaning routines, etc.). For this purpose, school and classroom checklists were prepared for the characterisation of the school buildings and classrooms (e.g. building materials,

[1] Corresponds to International Study of Asthma and Allergies in Childhood (ISAAC) Phase II criteria, where children of this age group were chosen because they are known to participate and perform satisfactorily in all proposed tests.

ventilation systems, furnishings and fittings, cleaning products, outdoor sources, etc.) in order to provide sufficient descriptors to support the overall analysis (Table 2) (see annex 3.1).

Table 2. Main sections of the SINPHONIE school and classroom checklists

School checklist	Classroom checklist
Outdoor characterisation	Indoor characterisation
Construction characterisation	Visible problems
Ventilation characterisation	Heating characterisation
Past occurrences or visible problems	Natural/mechanical ventilation
Building use of IAQ sources	Classroom use of IAQ sources
Building information for modelling purposes	Classroom information for modelling purposes

Concerning the impact of transportation and traffic on IAQ, vehicles produce some air pollutants that are considered as unique tracers. The level of air pollutants produced by transport in the proximity of school buildings can be calculated with sufficient accuracy using existing atmospheric modelling techniques. The methodology developed within the framework of SINPHONIE is based on a statistical analysis of the measurements of traffic-related pollutants both outdoors and indoors. This analysis is an integral part of the deterministic approach followed in order to identify the mass exchange flow rates between the indoor and outdoor air that are responsible for the physical transfer of outdoor pollutants indoors, and vice versa. The so-called transfer functions resulting from the above methodology may lead to a credible and validated prediction model for indoor pollutants in buildings for use in the analysis and theoretical investigation of cases with variable boundary conditions.

In addition to the complexity of sources and interactions to be taken into account in the school environment, another recent concern has emerged: the potential impact of climate change. Climate change is expected to raise ambient temperatures, extend the length of hot spells and increase the frequency of heat waves and the heat island phenomenon in specific urban zones. It is therefore important to evaluate its impact on the quality of the indoor environment in school buildings. The changed atmospheric conditions may affect indoor conditions and the airflow through the windows, as well as the concentration of pollutants. In order to evaluate the impact of climate change on the indoor environment various climate scenarios were investigated within SINPHONIE.

An exhaustive analysis was carried out in order to compile the most recent climate data and air quality simulations that have been generated for Europe. Several projects have been implemented under the 6th and 7th EU Framework Programmes [27, 28] that have dealt directly with climate change simulations across Europe at high spatial resolution.

Simulations were then carried out to evaluate the possible change in airflow rates through windows as well as the possible increase in concentrations of indoor pollutants in the SINPHONIE schools. Sensitivity analyses were also carried out to evaluate the potential impact of climate change on the main parameters affecting IAQ in school environments.

The impact of climate change on indoor air temperature was investigated using regional climate models. The aim was to predict changes in temperature by season and by month on the basis of regional climate models, and to predict the consequences on the thermal comfort of children at school.

Higher global temperatures will affect the different parts of the world to different extents. In this study, the temperature changes for Europe were characterised by the HadGEM1 climate model [57]. This was developed in 2006 and was used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Overheating in passive-ventilated schools, built according to design typologies prevalent in Europe, was also assessed. For this purpose, energy-temperature models of each school typology were simulated using weather files for present weather conditions and projected future conditions in London, Paris, Athens, Porto, Budapest and Stockholm. The climate data for the selected cities were used to simulate and predict internal thermal conditions in schools by means of building thermal modelling. Prototypes of typical building typologies (Victorian, open air, contemporary, passive and energy efficient) were used to calculate their energy consumption by using whole building energy model simulations on Energy Plus software.

3.5 Indoor and outdoor air monitoring procedures and protocols

The study included walkthrough surveys of school grounds, buildings and chosen classrooms, including indoor and outdoor air sampling to measure a number of key pollutants and parameters recognised as important IAQ-related health drivers by WHO and the EC and required in the technical specifications of DG SANCO's call for tender (Table 3).

Table 3. Chemical, physical and comfort parameters, microbiological agents and allergens evaluated

Chemical parameters	Physical and comfort parameters	Microbiological agents and allergens
Formaldehyde	Temperature	Endotoxins
Benzene	Relative humidity	Fungal and bacteria DNA
Trichloroethylene	CO_2	*Penicillium/Aspergillus/Paecilomyces variotii group; Aspergillus versicolor; Cladosporium herbarum; Alternaria alternata; Trichoderma viride; Streptomyces spp.; Mycobacterium spp*
Tetrachloroethylene	Ventilation rate	
d-limonene, α-pinene		
Naphthalene		
NO_2		
$PM_{2.5}$, PM_{10}		
Ozone		Allergens
Benzo(α)pyrene		Cat, dog and horse allergens and house dust mites (Der p1, Der f1)
CO		
Radon		

Because of the less convenient and less accessible sampling method that is needed for benzo(α)pyrene detection, this compound was monitored in only a few schools. Concentrations in this limited dataset cannot therefore be considered as representative for the geographical area covered by SINPHONIE, and are not further discussed in this report. Because PM_{10} was monitored optically, the data provide valuable information for schools, showing the PM variation over time. However, since the outcomes of optical PM measurements (expressed in $\mu g/m^3$) cannot be considered as absolute values, the reported and evaluated PM levels in this document are restricted to $PM_{2.5}$ concentrations (measured using the reference method - that is, gravimetrical analysis (see annex 3.3).

3.5.1 Chemical, physical and comfort parameters

A total of 16 key chemical, physical and comfort parameters were measured per school in parallel in each of the three classrooms, and at one point outdoors during the same period.

Since no reference methods for indoor air monitoring are currently available, a list of SINPHONIE preferred methods was established, based on the criteria recommended in the International Organization for Standardization (ISO) 16000 series and in compliance with criteria specified in ISO 16000-1 [47].

Where there was no recommended method in the ISO 16000 series for a specific compound, the preferred method is that for indoor and/or workplace environments and described in the guidelines of the ISO, the American Society for Testing and Materials (ASTM), European Standards (EN) or the European Committee for Standardisation Technical Committee (CEN TC). Where no suitable method was described for indoor environments, or where the practical implementation (field studies) of the method did not correspond to SINPHONIE requirements, the preferred method was an ambient air reference method or a method that has been published in a peer-reviewed journal.

Diffusive samplers were used for several of the target chemicals (benzene, trichloroethylene, tetrachloroethylene, formaldehyde, pinene, limonene, NOx, ozone), followed by the relevant analytical procedures (spectrophotometry, ion chromatography [IC], liquid chromatography [LC] or gas chromatography [GC]). Carbon monoxide and CO_2 were measured continuously by a low-cost logger, and PM_{10} and $PM_{2.5}$ by optical light scattering. In addition, $PM_{2.5}$ was measured gravimetrically after pumped sampling over a filter. Benzo(α)pyrene and naphthalene were analysed by gas chromatography-mass spectrometry (GC-MS) after pumped sampling over a tube. Radon concentration was measured by a passive method (track counts on exposed film). Ventilation rates were calculated based on CO_2 measurements (see annex 3.3).

To assess levels of exposure to substances that are perceived to cause chronic health effects, the air sampling in schools covered a five-day period (the school week, from Monday morning until Friday afternoon). Reported levels are time-averaged values (e.g. resulting from passive air sampling), except for CO (which causes acute health effects, thus a short-term assessment was more suitable). Because of the close relationship between $PM_{2.5}$ and occupancy density (m^2/child), $PM_{2.5}$ samples for gravimetric analysis were collected during teaching hours. These were set for a period of eight hours per day, starting at 8 a.m. and ending at 4 p.m. for all involved schools (see annex 3.3).

Guidelines for the installation of the sampling equipment were formulated with respect to ISO 16000-1 and presented at the SINPHONIE environmental/health training session (in May 2011) at the premises of the JRC's Institute for Health and Consumer Protection (IHCP) in Ispra. More than 80 participants attended the training from 39 health and environmental institutions in 25 European countries. Emphasis was placed on harmonisation and compliance with safety measures in the schools and classrooms. A SINPHONIE field studies booklet was prepared and automatic sample codes were generated for each country/school/classroom/sample combination to provide a practical guide for the registration of data generated during the field studies.

As a follow-up to the training, and in order to enhance data comparability, the SINPHONIE quality control and quality assurance (QA/QC) strategy was formulated at three levels.

- The first level of QA/QC involved the collection of a duplicate sample using the SINPHONIE preferred method in the event that an alternative method was used in the field. This independent reference sample (according to EN 482:2010) [18] provided information on the accuracy of the alternative method. The alternative method could then be considered as a representative (in terms of the validity of the IAQ parameter value measured), if it complied with the requirements for expanded uncertainty, as described in EN 482:2010. Since formaldehyde, VOCs, ozone and NO_2 were measured using the SINPHONIE preferred sampling (passive air sampling) and analysis method throughout, this first level of quality assurance turned out not to be applicable.
- The second level of QA/QC was the internal quality control of the participating laboratories in order to evaluate the accuracy of the analysis procedures. This involved various inter-laboratory trials for the analysis of benzene, formaldehyde and NO_2 (the last only for those laboratories undertaking the in-house analysis of NO_2). The participation rate was 85%, although data coverage turned out to be even higher since some countries subcontracted other labs within the SINPHONIE consortium for chemical analysis. Statistical analysis of the outcomes was carried out according to ISO Standard 5725 [53]. All participating laboratories received a report containing the outcomes of the ring trial. Laboratories classified as outliers/stragglers were individually contacted to try to identify the sources of error and to implement corrective actions.
- For the third level of QA/QC, each of the SINPHONIE centres organising fieldwork collected 10% of the samplers in duplicate. An acceptable bias below or equal to 30% between the duplicate samples was obtained for the majority of the duplicates. A limited number of institutes did not collect duplicates, and very few laboratories obtained a bias exceeding 30% (see annex 3.6).

Bearing in mind that there were 456 sampling sites in the SINPHONIE main study (114 schools, and in each school three indoor sites and one outdoor site), very few samples were lost during the fieldwork or analysis. In total, 4.4% of the radon results, 2.6% of $PM_{2.5}$ measurements and 2% of the VOCs concentration assessments failed. In addition, 1.8% of the CO measurements are missing and 1.5% of the ozone samples were lost. For formaldehyde and NO_2, less than 1% of the data is missing. All reported SINPHONIE air quality values have been blank corrected, except for physical and comfort parameters.

3.5.2 Microbiological agents and allergens

Thirteen different microbiological agents and allergens were targeted in the SINPHONIE main study. They are listed by analyte group in Table 4.

Table 4. Microbiological agents and allergens measured in SINPHONIE, type of analysis (and analysing centre) and number of classrooms and samples analysed

Biological agent targeted	**Laboratory analyses**	**No. classrooms/No. samples successfully analysed**
Endotoxin	Limulus Ameobocyte Assay (NIEH)	331/310
Microbial groups *Penicillium/Aspergillus/ Paecilomyces variotii group; Aspergillus versicolor; Cladosporium herbarum; Alternaria alternata; Trichoderma viride; Streptomyces spp.; Mycobacterium spp.*	Quantitative PCR (THL)	334/319
Allergens	ELISA (UU)	334/333
Cat allergen, dog allergen horse allergen, house dust mite (Der p1, Der f1)	ELISA (UU)	111/111

The microbiological agents measured in the SINPHONIE study were selected on the basis of existing knowledge of the suggested adverse health effects of the target compounds and/or their link to indoor conditions of moisture damage and dampness, the latter being strongly linked to the poor health of building occupants.

Microbiological contaminants measured in SINPHONIE schools refer to three different groups of agents. Endotoxin is probably the one microbial agent most commonly measured from indoor sample materials in epidemiological studies on asthma and allergy, due to its known properties as an inflammatory agent and respiratory irritant. Endotoxin is also frequently used as a surrogate to estimate total microbial exposure indoors, which is, however, a very debatable approach. Fungal and bacterial groups in our living environments play an ambivalent role in human health and disease, provoking both beneficial and adverse effects in exposed people. This ambivalence in the interaction between microbes and humans calls for a more specific and detailed description of microbial exposures. Today, molecular approaches, such as quantitative PCR, allow the quantification of microbial species, genera or larger taxonomic groups via the detection and enumeration of specific DNA targets. Such DNA-based approaches do not require the viability and cultivability of the respective microbes, which has always been a serious limitation in cultivation-based approaches for the enumeration of viable microbes. This means that not only “live” microbes but also dead cells and cell fragments - known also to be relevant to human health - can be detected, as long as DNA is still present.

The following microbiological agents and allergens were targeted in SINPHONIE: the fungal species *Aspergillus versicolor* (Avers), *Cladosporium herbarum* (Cherb), *Alternaria alternata* (Aaltr) and *Trichoderma viride* (Tviri); a larger fungal group comprising *Penicillium* spp./*Aspergillus* spp./*Paecilomyces* spp. (PenAsp); as well as the two bacterial genera *Streptomyces* spp. (Strep) and *Mycobacterium* spp. (Myco) (see Table 4).

No Europe-wide guidelines exist with respect to monitoring non-infectious biological contaminants indoors. Very few national guidelines are available, and none of them are health based, with the measurements typically relying on semi-ideal sampling and analysis approaches (WHO 2009) (see annex 3.12). In SINPHONIE, we chose to analyse microbial agents using molecular, state-of-the-art approaches that can potentially replace traditional, cultivated-based methods for the enumeration of viable microbes in short-term air samples. The SINPHONIE project thus provides a basis for the future development of guidelines on indoor biological contaminants by establishing an extensive dataset of biological compounds measured using molecular methods in a large number of classrooms in schools across Europe.

Biological contaminants in SINPHONIE were determined primarily from settled dust samples, collected in three classrooms per school during the heating season (see Table 4). While active air sampling would be the most suitable for an exact assessment of human exposure, the techniques and resources required for active air sampling for microbes were beyond the possibilities of the survey within SINPHONIE. Settled dust is considered a long-term integrated sample that represents airborne exposure. This sample material is easily collected without the need for very specific equipment. The sampling approaches chosen in SINPHONIE guaranteed that the sampling campaigns could be conducted in all participating study centres. Details of the sampling approaches specific to each of the biological agents targeted are provided in the protocols for the sampling of biological contaminants in SINPHONIE schools (see annexes 3.7, 3.9, 3.10 and 3.11). Standardised sampling protocols and respective methodologies were presented at the SINPHONIE training session in May 2011.

The sampling was performed once in each study centre (during the heating season) in the course of the SINPHONIE exposure assessment, in connection with other measurements. Each study centre was responsible for performing the actual sampling in their study schools, and for the short-term storage and shipment of the samples to the analysing centres. Field workers were centrally trained on the sampling protocol in order to guarantee standardised sampling between centres. Indoor dust was collected in the schools/kindergartens using three approaches, adapted for the optimal detection of the different biological agents: (1) settled dust from surfaces above floor level was vacuumed into dust sampling socks; (2) electrostatic dust fall collectors were used for the passive sampling of airborne dust onto electrostatic wipes; and (3) floor dust and dust from other surfaces was also collected using vacuum cleaners with ALK adaptors and filter cassettes.

The processing of the dust samples and their analysis for the different biological agents were centralised in laboratories specialising in the respective techniques. Endotoxin was analysed using the Limulus Ameobocyte Assay at NIEH, Hungary; specific fungal and bacterial groups were analysed at the THL, Finland, using quantitative polymerise chain reaction (qPCR); and allergens were analysed at Uppsala University (UU), Sweden, via enzyme-linked immunosorbent assay (ELISA). The list of seven analytes measured at THL was slightly modified from the initially planned list, based on recent results in the assessment of microbial exposures undertaken for other studies. The planned analysis of ergosterol had to be substituted due to technical difficulties with the analytical machinery, with one additional fungal marker assayed via qPCR.

The test for bacterial endotoxins (BET) is used to detect or quantify endotoxins from Gram-negative bacteria using amoebocyte lysate from the horseshoe crab (*Limulus polyphemus,, Tachypleus tridentatus*). Endotoxin analysis was performed using the chromogenic technique, based on the development of colour after the cleavage of a synthetic peptide-chromogen complex. Endotoxin analysis was carried out in a suitable dilution in pyrogen-free water. Standard endotoxin stock solution was prepared from a United States Pharmacopeia (USP) endotoxin reference standard calibrated to the current WHO international standard.

For qPCR analyses, dust samples were homogenised in terms of size, aliquot scaled and weighed. As described above, DNA was isolated from 20 mg dust samples with bead beating [89]. As an internal control for qPCR, 2×10^6 spores of *Geotrichum candidum* strain were added to the samples before starting the extraction. To quantitatively measure the concentration of certain microbial groups or species in the dust samples, seven qPCR assays were performed. The assays comprised representatives of five fungal and two bacterial genera. The assays were specific for one species (*Aspergillus versicolor, Cladosporium herbarum, Penicillium brevicompactum* or other fungal target), several species of one genus (*Trichoderma viride/atroviride/koningii*), one genus (*Mycobacterium* spp., *Streptomyces* spp.) or several genera (*Penicillium/Aspergillus/Paecilomyces variotii*). The qPCR laboratory analyses and calculations were performed as described by Kaarakainen et al. [59].

For allergen analyses, samples of settled dust were weighed (100 mg) and extracted in 2 ml of phosphate-buffered saline containing 0.05% Tween 20 (1/20 W/v) for two hours at room temperature. Allergen levels were determined using two-site sandwich ELISA for house dust mite (Der p1, Der f1), cat (Fel d1), dog (Can f1) and horse allergen (Equ cx) using monoclonal antibodies. Allergen concentrations were expressed as ng/g dust, except for horse allergen concentrations, which were expressed as units/g dust, where 1 unit is equal to 1 ng protein of a horsehair and dander extract used as standard. Protein determination was performed on the standard with the micro-BCA method using BSA as standard. Cat and dog allergens were analysed from all classrooms sampled in the SINPHONIE schools, while horse allergens and dust mites were analysed in one classroom in each school.

Table 4 shows the number of samples successfully analysed in relation to the number of samples collected (classrooms monitored), with the percentage of failed analyses being well below 10% in all cases. The final list of the 13 analytes measured in the SINPHONIE main study provides an excellent overview of the occurrence and levels of biological contaminants in school environments across Europe, while the approach of using centralised analyses of biological agents, in combination with the standardised methods used for sample collection, guaranteed highly comparable data.

The SINPHONIE main study was complemented by a side study exploring the contribution of outdoor air to indoor microbial levels. This side study was carried out in only a very limited number of schools, since the specific task of comparing indoor and outdoor levels of biological agents requires active air sampling. Active air sampling campaigns carried out in parallel in three classrooms and one outdoor location, using Button inhalable aerosol samplers, were performed in schools in Finland and Poland during the heating and non-heating seasons. In the course of a school visit, active air samples ("button sampling") were collected during teaching hours on a regular school day. Pumps and button samplers were distributed to the study classrooms and the outdoor location in the morning and sampling was started. After stopping the active air sampling, settled dust was collected from the study classrooms from surfaces above floor level with a vacuum cleaner and dust sampling socks. The sample materials were analysed centrally at THL, using qPCR to target specific bacterial and fungal groups, as described in detail above.

3.6 Case studies on targeted indoor air quality issues

The case studies were selected to focus on specific aspects relating to IAQ in classrooms (either data gaps or specific aspects of the school environment that may have an impact on IAQ in schools).

Table 5. Case studies and partners/countries involved within SINPHONIE

Case study	Partners/countries involved
Effectiveness of ventilation to enhance IAQ	VITO (Belgium); UCL (UK); IDMEC (Portugal)
Effectiveness of abatement measures to improve IAQ	VITO (Belgium); CSTB (France)
Source apportionment of chemical emissions from consumer/building products	VITO (Belgium); IDMEC (Portugal); UOWM (Greece)
Indoor air quality and seasonal variations	THL (Finland); CSTB (France); IV (Serbia); UOWM (Greece); UBA (Germany)

Because of the required resources and practical implications, these studies could not be undertaken in all of the SINPHONIE schools. However, because of their potential significance in abatement or source apportionment, specific studies were undertaken in a smaller subset of the SINPHONIE schools, or at laboratory scale. The IAQ issues addressed in the case studies are listed in Table 5.

3.6.1 Effectiveness of ventilation to enhance indoor air quality

This case study, based on field measurements, assessed the effectiveness of various ventilation strategies adopted across Europe: natural, mechanical and mixed mode. In order to evaluate the effectiveness of the various strategies for enhancing IAQ in school buildings, three partners (UCL, UK; VITO, Belgium; and IDMEC, Portugal) focused their work on the key aspect of strategies for effective ventilation (see annex 3.6).

Effectiveness of various natural ventilation strategies: Impact of seasonal variations

This study was carried out in five primary schools and one kindergarten. All schools used natural ventilation, and in addition one school used mechanical exhaust ventilation controlled by a CO_2 sensor with manual override. A total of 18 classrooms were monitored, three in each school, and one outdoor site on the school premises. The assessment parameters included PM, VOCs, NO_2, ozone and bacteria, which were investigated during the heating season (November to January) and non-heating season (April to June) of the 2011/2012 school year.

Effectiveness of natural ventilation in schools: Impact of different ventilation interventions

The main aim was to investigate the effectiveness, in terms of CO_2 concentration control, of different ventilation options adopted in a traditional, naturally ventilated school located in the north of Portugal, and in particular to: 1) study the evolution of indoor CO_2 concentration levels while following the corresponding air changes per hour (ach) for several window/door/ventilation-specific opening conditions ("arrangements") during non-occupancy periods, teaching periods and breaks; 2) analyse the impact of the above options on IAQ parameters and verify their compliance with WHO IAQ guidelines and Portuguese regulation; and 3) formulate proposals for strategies to mitigate high CO_2 concentration values by the intermittence of the sources and/or the intermittence of the intensity of the ventilation (ach).

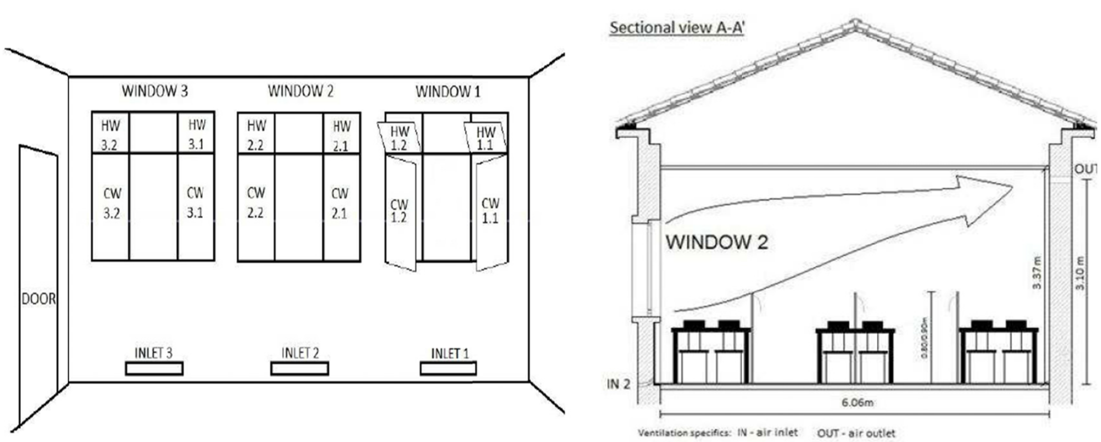


Figure 2. Identification of openings in the south facade and air circulation: classroom section view

The work was carried out in a state primary school located in Vila Nova de Gaia in the Porto metropolitan area, north of Portugal, between April and May 2012. Taking advantage of the typically moderate and sunny Atlantic-type climate, the school, like the great majority of Portuguese schools of this level, is naturally ventilated and its main glazed facade is fully south oriented.

For the purposes of this study, a classroom located on the first floor oriented towards the south was selected because of already existing specific natural ventilation openings below the windows.

Measurements took place over two weeks and were performed according to the following steps:

1. A grid of sampling points at the breathing level of pupils was established.
2. A grill of sampling points at the breathing level of pupils (sat down) has been established.
3. A schedule was planned for the different configurations of opening arrangements during the occupancy and non-occupancy periods.
4. The air changes per hour (ach), using CO_2 as a tracer gas, was measured under different arrangements.
5. Measurements were made of ventilation and specific IAQ parameters, temperature and relative humidity during teaching periods and normal occupancy under selected opening arrangements.

Effectiveness of different mechanical ventilation systems: Comparison of different ventilation types

The simultaneous assessment of ventilation effectiveness in three mechanically ventilated classrooms (each equipped with a ventilation system) is clearly defined and includes: indices representing the ability of a system to exchange the air in the room (such as air change efficiency and local air change index); and indices representing the ability of a system to remove airborne contaminants or their proxies (contaminant removal effectiveness and local IAQ index).

Three kindergarten classrooms were selected in a school located in the city of Antwerp, Belgium:

- Class-1 had a heat recovery ventilation system (supply air filter EU7/F7; 22 m^3/h.person; ventilation rate 2.72 h^{-1});
- Class-2 was aerated through window opening (maximum 0.01 $m^2.m^{-3}$); and
- Class-3 was aerated through large sliding doors (maximum 0.05 $m^2.m^{-3}$).

Particulate matter was studied ($PM_{2.5}$ MS&T Area Sampler and SP-280E pumping unit, Air Diagnostics and Engineering) and optically (Grimm Dust Monitor, 1.108-Filter-check™ Grimm Technologies, according to CEN TR 16013-2). Samples of $PM_{2.5}$ were collected during teaching hours (from 8 a.m. until 4 p.m.), and the mass concentration was assessed according to NBN-EN-12341 [45]. Volatile organic compounds were collected indoors and outdoors using Radiello diffusive tubes (Code130, Fondazione Salvatore Maugeri). After chemical desorption, GC-MS analysis was carried out using an accredited method according to ISO 17025. Indoor relative humidity, temperature and CO_2 were monitored using a calibrated Catec Klimabox and are reported as average teaching-hour concentrations.

3.6.2 Effectiveness of abatement measures to improve indoor air quality

Abatement measures may improve IAQ in schools by selectively reducing the indoor level of one or more pollutants. This case study therefore aimed to evaluate the effectiveness of a purification product used to reduce indoor air pollution in the classroom.

An Internet search for air purification products available on the European market was performed to select a product suitable for application in schools (see annex 3.6). The focus was on a sorptive board, since these plaster walls are fairly easy to install in classrooms and can reduce formaldehyde concentrations indoors.

In glass emission test chambers of 0.057 m^3 (designed with respect to ISO 16000-9) [52], the active material (Material A) and a non-active equivalent material (Material B) were exposed to: 1) formaldehyde, the compound which is supposed to be removed from the air by this product; and 2) typically occurring indoor pollutants (toluene, benzene, limonene), although these are not the compound targeted by the abatement product. At a loading factor of 0.38 m^2/m^3, the indoor concentrations as well as the inlet air concentrations of the test chambers were measured simultaneously on day 1, day 3, day 7, day 14 and day 28 (respecting ISO 16000-23 and ISO 16000-24) [48, 49]. All measurements were performed respecting ISO 16000-3 and ISO 16000-6 [50, 51].

The next step was to evaluate the performance of the material in a controlled real-life exposure test chamber in the experimental house MARIA[2] [88]. A surface of 14 m^2 of Material A was installed on the walls of the room. This surface was calculated to reach a loading factor of 0.43 m^2/m^3 in the experimental room, which is equivalent to the loading factor that would be obtained on the ceiling of SINPHONIE classrooms if entirely covered by these boards. Aldehydes and VOCs were monitored using Radiello passive samplers during three consecutive weeks (seven days) in the experimental room:

- period 1: without active material inside the room;
- period 2: with active material inside the room; and
- period 3: without active material inside the room.

A field blank was placed in the room during each period. Duplicates were placed during period 1. Ambient parameters (temperature and relative humidity) were monitored and measured continuously during the same periods.

[2] Experimental environmental house at CSTB, France.

3.6.3 Source apportionment of chemical emissions from consumer/building products

The indoor classroom environment is affected by the use of consumer products related to children's activities, as well as classroom furnishings and cleaning activities. Emissions from some of these products may have an impact on IAQ. This case study focused on the identification and quantification of VOCs emitted by a selection of consumer products and potentially contaminating the indoor air in the classroom.

After a classroom walkthrough, five products commonly used in classrooms were selected and product emissions tests were performed. The following products were studied:

- a wooden chair for children: glued and varnished;
- pens for writing on a white board;
- gouaches used by children for handcraft activities;
- crayons; and
- a wooden game.

Product emissions tests were performed simulating the indoor environment in terms of temperature, relative humidity and ventilation rate, representing classrooms in different European climatic zones in a 0.916 m^3 emission test chamber (Vötsch VCE 1000 Classic) or a small test chamber of 0.255 m^3. The results were evaluated in relation to the lowest concentrations of interest (LCI) values (toxicologically based threshold values) used in Germany and France.

The Field and Laboratory Emission Cell (FLEC) for materials emissions testing was also used for on-site emissions measurements of selected building materials and certain consumer products in a school environment. The data obtained were then used to identify the sources and estimate the possible exposure of both teachers and children. Additionally, based on FLEC on-site measurements, the contribution of building material emissions to IAQ was estimated (source apportionment).

3.6.4 Indoor air quality and seasonal variations

Different outdoor conditions, meteorologically as well as related to the ambient air quality, may have different impacts on IAQ in schools in the various European geographical areas. The objective of this case study was to assess and compare IAQ in schools during the heating and non-heating seasons in each of the SINPHONIE geographical clusters. Measurements were taken during the non-heating season in 18 schools. The distribution over the geographical clusters is shown in Table 6.

Measurements during the non-heating season were organised between August 2011 and September 2011 and between May 2012 and June 2012 (depending on the start of the new school year and the climatic conditions). These measurements took place in the same schools at least two months before and after the measurements taken during the heating season (as part of the SINPHONIE main study). Samplers and monitors were installed at exactly the same sites indoors and outdoors during both campaigns in order to achieve maximum comparability (with the exception of the Serbian school, in which the outdoor site used during the first campaign had to be transferred from the playground to a balcony for the second campaign). The applied sample collection techniques and analysis methods were unchanged.

Table 6. Number of schools per SINPHONIE cluster and partners/countries involved in the case study "Indoor air quality and seasonal variations"

		Partners/countries involved	No. of schools
Cluster 1	Northern Europe	THL (Finland)	3
Cluster 2	Western Europe	UCL (UK)	5
		CSTB (France)	2
		UBA (Austria)	2
Cluster 3	Central-Eastern Europe	IV (Serbia)	3
Cluster 4	Southern Europe	UOWM (Greece)	3

3.7 Health outcomes assessed by questionnaire

3.7.1 Questionnaires and tools

Questionnaires

In the context of SINPHONIE WP4, questionnaires were specifically developed for the assessment of children's and teachers' respiratory health; the assessment of their perception of IAQ in the school building/classroom; the evaluation of risk factors related to IAQ; and the identification of possible confounders regarding children's domestic lifestyles.

The questions about children's health status were mainly derived from the standardised validated questionnaire of the International Study of Asthma and Allergies in Childhood (ISAAC) [5]. The development of the questionnaires was partly based on standardised questionnaires used in previous recent European projects, such as the HESE study [43] and the SEARCH study [20], in order to collect information on common risk factors at home.

Five questionnaires were prepared (see annex 4.1):

- The *questionnaire for pupils* was used to collect information on pupils' respiratory/allergic symptoms/diseases, perceptions of air quality inside/outside the school, and perceptions of the influence of poor air quality on school performance. In kindergartens and classrooms with younger children, or in schools where the completion of the questionnaire by pupils would not be appropriate, only a single questionnaire for parents was used. This questionnaire was administered during school hours.
- The *questionnaire for parents* was used to collect information on respiratory/allergic symptoms/diseases and children's dietary intake, the more common home risk factors (e.g. smoking habits, pet keeping, presence of moulds/dampness, cooking/heating systems, gas appliances, cleaning products, etc.), and familiarity with any respiratory/allergic diseases. This self-administered

questionnaire was designed to investigate both life-long and recent symptoms, dwelling characteristics and lifestyles.

- The *questionnaire for teachers* was used to collect information on respiratory/allergic symptoms/diseases and dietary intake, perceptions of air quality inside/outside the school, and perceptions of the influence of poor air quality on school performance, more common home risk factors (e.g. smoking habits, pet keeping, presence of moulds/dampness, cooking/heating systems, gas appliances, cleaning products, etc.), familiarity with any respiratory/allergic diseases, and knowledge/management of school issues related to air quality and to children with asthma. An innovative tool, this questionnaire was elaborated to address the lack of any information relevant to teachers' respiratory health and perceptions of IAQ in the scientific literature.
- One questionnaire about each monitored classroom was completed, if possible with the cooperation of all teachers working in that classroom, to assess the physical characteristics of the classroom, cleaning procedures, furnishings and perceptions of IAQ.
- The questionnaire about the school was used to collect information on school building characteristics, with particular attention to the features of the ventilation system. It was completed by the school principal.

Tools (attention/concentration test and absenteeism)

- *Attention/concentration test*

This test was elaborated along with a document for variable encoding and data entry in order to harmonise the fieldwork for subsequent statistical analyses (see annex 4.4).

The test comprised two parts. The first was a series of simple mathematical tests, for which the percentage of correct answers (score 1a) was evaluated. The second part was a logical test with 119 elements to be solved within 120 seconds. Again, the percentage of correct solutions (score 1b) was evaluated. These two parts had to be completed during the first lesson of the day and repeated during the last lesson of the day (score 2a and score 2b). The difference between the two trials was expected to reflect the decreased attention and concentration capacity at the end of the teaching day, influenced by various factors of the school environment.

Scores observed in the morning and in the afternoon, as well as the differences between them (Diff 2a-1a and 2b-1b) were analysed separately in association with the various classroom characteristics.

- *Absenteeism*

A tool for assessing absenteeism from schools and kindergartens (register of absenteeism) was developed (see annex 4.2). Attendance report forms were prepared, for completion by a teacher (or other instructed person) for each class, in order to record illness-related absences among children for a defined period. Alongside the name of the child and the date of the absence, the reason for the absence was reported according to a standardised format, in which absence was classified as being related to respiratory or other illness, or not illness related, according to protocol-specified definitions. Respiratory illness was defined according to the health questionnaires.

Absenteeism among children was recorded for four months between November 1, 2011 and February 29, 2012, either in a personalised way (a child's presence or absence each day) or, if the school or parents did not give their consent, at class level (daily number of absent children per class).

3.7.2 Definition of health and related variables

Table 7 lists recent (<3 months) symptoms by organ in children as assessed via the parents' questionnaires and the question "During the past three months, has your child had any of the following symptoms?". The possible replies were: (1) No, never; (2) Yes, sometimes (1 to 3 times/month); (3) Yes, often (1 to 4 times/week); and (4) Yes, daily.

Table 7. Recent symptoms by organ in children

Symptom/disease by organ (3 months)	***Question*: "During the past three months, has your child had any of the following symptoms?"**
Skin	
Hand rash	Skin rash on hands or forearms
Face rash	Skin rash on face or neck
Eczema	Eczema (if "yes", where?)
Hand itch	Itching on hands or forearms
Face itch	Itching on face or neck
Eye	
Eye irritation	Eye irritation (redness, dryness, itching)
Eye swelling	Swollen eyes
Nose	
Runny nose	Runny nose/nasal phlegm
Blocked nose	Nasal obstruction/blocked nose
Lower airways	
Dry throat	Dry throat
Sore throat)	Feeling of getting a cold
Irritative cough	Irritative cough
Shortness of breath (SoB)	Breathing difficulties
Systemic	
Feeling cold	Sore throat
Feeling tired	Feeling tired or out of sorts
Headache	Headache
Nausea	Nausea
Symptom(s) improve on returning home	Do any of these symptoms improve when your child is away from school ("yes", "no", "do not know")

Remark: in the meta-analyses, all three kinds of "yes" replies were coalesced into a single "yes" response

Table 8 lists symptoms and diseases ever/past year/past month, as well as a question on wheezing in the past 30 days, assessed in children (using the ISAAC questionnaire) [5] and reported by parents. Symptoms and diseases were grouped by typology (e.g. asthma-like, rhinitis-like, etc.). The questions on wheezing in the past 30 days and asthma attacks in school were considered highly pertinent to the study of the effects of environmental exposures at school, the former because of its timing compared to *in situ* environmental assessments, the latter because of the SINPHONIE focus on health in schools.

Table 8. Symptoms/diseases in children ever, past year and past month

Symptom/disease	***Question***
Asthma-like	
Wheezing (ever)	Has your child ever had wheezing or whistling in the chest at any time in the past?
Wheezing (<12 months)	If "yes": In the past 12 months has your child had wheezing or whistling in the chest?
Wheezing (<30 days)	If "yes": In the past 30 days has your child had wheezing or whistling in the chest?
Doctor-diagnosed asthma	Has your child ever had asthma diagnosed by a doctor?
Asthma in school	If "yes": Has your child ever had an asthma attack while at school?
Rhinitis-like	
Runny/blocked nose ever†	Has your child ever had a problem with sneezing or a runny or blocked nose when he/she DID NOT have a cold or the flu?
Nasal allergy (<12 months)†	If "yes": In the past 12 months, has your child had a problem with sneezing or a runny or blocked nose when he/she DID NOT have a cold or the flu?
Eye irritation (<12 months)†	If "yes": In the past 12 months has this nose problem been accompanied by itchy, watery eyes?
Nasal allergy (ever)	Has your child ever had a nasal allergy, including hay fever?
Doctor-diagnosed nasal allergy	If "yes": Was the allergy confirmed by a doctor?
Skin diseases	
Itchy rash (ever)(for 6 months)	Has your child ever had an itchy rash that was coming and going for at least 6 months?
Eczema (ever)	Has your child ever had eczema?
Other respiratory diseases apart from cold	
Night dry cough (<12 months)	In the past 12 months has your child had a dry cough at night, apart from a cough associated with a cold or chest infection?
Coughing episodes	Does your child have a cough on most days (four or more days per week), apart from common colds?
Phlegm episodes	Does your child have phlegm on most days (four or more days per week), apart from common colds?

† Not occurring due to a cold

Additional asthmatic and allergic characteristics, as well as stress at school, were looked for in children, as shown in Table 9. Questions on asthma and allergies were drawn from the ISAAC questionnaires [5], while the question on stress was taken from the HESE study [43]. These questions were answered by the parents.

Table 9. Asthma and allergy characteristics and stress at school among children

Asthma and allergy characteristics	
Any drug for asthma <12 months‡	No, never
	Yes, occasionally
	Yes, regularly
Family history of any allergy	No
	Yes
Pollen allergy	No
	Yes
Food allergy	No
	Yes
Stress at school§	High§
	Low§

‡ Anti-asthma medications included: short-acting beta-agonists, long-acting beta-agonists, inhaled corticosteroids, theophillyne, cromon.

§ Low: score 0–4, medium: score 5–7, high: score 8–10

Table 10. Symptoms and diseases among teachers

Symptom	Question
Asthma-like	
Wheeze (anytime) (<12 months)*	In the past 12 months have you had wheezing or whistling in your chest at any time?
Wheeze (<12 months)†	If "yes": Have you had this wheezing or whistling when you did not have a cold?
Asthma (ever)	Have you ever had asthma?
Doctor-diagnosed asthma	If "yes": Was asthma confirmed by a doctor?
Asthma (<12 months)	If "yes": In the past 12 months have you had attacks of asthma?
Rhinitis-like	
Nasal allergy (ever)	Have you ever suffered from nasal allergies, including hay fever, or rhinitis?
Other respiratory diseases	
Cough/phlegm episodes	Do you cough/bring up phlegm on most days for as much as three months each year?

* This question was not analysed but was kept in the list because the following question was linked to it

† Not occurring due to a cold

Table 10 shows the list of symptoms and diseases presented in the analysis of teachers and the original question from the teachers' questionnaire. Additional asthmatic and allergic characteristics were also looked for in teachers, as shown in Table 11.

Table 11 shows the questions on asthma and allergy characteristic in teachers. The questions for teachers were drawn from the European Community Health Study (ECRHS) (see annex 4.1).

Table 11. Asthma and allergy characteristics in teachers

Characteristics	Categories
Family history of any allergy	No
	Yes
Any drug for asthma <12 months†	Never
	Yes, occasionally
	Yes, regularly

† Anti-asthma medications included: short-acting beta-agonists, long-acting beta-agonists, inhaled corticosteroids, theophillyne, cromon

3.8 Clinical monitoring procedures and protocols

The SINPHONIE study involved a great variety of countries and institutions with different levels of clinical expertise and resources. It was considered that acquiring expertise and equipment for environmental measurements should have precedence over clinical measurements when allocating the funds available locally from the project. Thus, while all the national centres were encouraged to perform as large a number of clinical tests as feasible, only questionnaires and spirometry were considered mandatory, and each country was left free to choose which other tests to perform, according to the expertise and resources available.

Lung function tests (spirometry) were performed according to European Respiratory Society (ERS)/American Thoracic Society (ATS) guidelines, using instruments compliant with the 2005 ATS/ERS standard of accuracy and calibrated daily according to the manufacturer's instructions. Lung function measurements involved the development of a protocol, including criteria for quality control. Spirometry was performed on all children in the selected classrooms, according to the protocol devised under SINPHONIE WP4. All the spirometers used had to be sent to a reference centre in order to be tested on a single group of volunteers to check for any inter-apparatus variability. The measured lung function parameters were forced expiratory volume at 1.0 second (FEV_1); forced vital capacity (FVC); the Tiffeneau index (the FEV_1/FVC ratio); peak expiratory flow (PEF); and forced expiratory flow 25% (FEF_{25}), 50% (FEF_{50}), 75% (FEF_{75}) and 25–75% (FEF_{25-75}). Lung function parameters were adjusted for the age, gender and height of the child, and in some analyses they were compared to predicted values according to a reference equation.

The additional facultative clinical tests and non-invasive biomarkers proposed in SINPHONIE aimed to evaluate the response of airway mucosa to different school indoor environments and to assess the existence of allergic sensitisation in a random sample of five children in each classroom in selected schools:

- exhaled nitric oxide (eNO) levels were measured using Niox-MINO (Aerocrine, Sweden);
- exhaled carbon monoxide (eCO) levels were measured using Smokerlyzer (Bedfont Scientific, UK);

- acoustic rhinometry was performed using the same device model (Acoustic Rhimometer A1, GM Instruments, Scotland) and the accompanying software according to the manufacturer's instructions;
- nasal lavage was performed in order to look for inflammatory markers (MPO[3], ECP[4], lysozyme[5], albumin); and
- exhaled breath condensate was examined (to look for inflammatory markers).A tear break-up time (TBUT) test was used to measure the time it takes for tears to break up in the eye. The TBUT can be determined after placing a drop of fluorescein in the conjunctival cul-de-sac and is used as a measure of tear film stability.Skin prick tests (SPT) were carried out according to a standardised protocol with a panel of common aeroallergens, representative of the more common allergens in each country. However, SPT posed particular problems in some centres, as local ethical committees considered it more than minimally invasive and refused permission to perform it in schools.

During the training that took place at the JRC-IHCP in Ispra in May 2011, all the procedures were explained, discussed, demonstrated and directly experimented by the technical staff from each country.

3.9 Statistical data analysis

The selected description/storage mechanism for data was structured in Microsoft Excel sheets (Microsoft Office Excel 2003). Information was collected on five "item types": countries; schools (primary schools and kindergartens); rooms (including outdoor); children; and teachers (see annex 5). Five methods of investigation were used to obtain data: given, for factual information on countries; obtained via checklists for factual information on both schools and rooms; obtained via measurements for rooms, both physical/chemical and biological; obtained via tests of children (both general and clinical health tests and attention tests); and obtained via questionnaires for school administrators on their schools. For the health test (general/clinical) data, acronyms were kept as attribute names.

As indicated above, different tools were used for children (at primary schools and kindergartens[6]) [91] and teachers when assessing environmental exposure and health outcomes. Different types of symptoms and diseases affecting different organs during the three months and in the year preceding the survey, and ever, were assessed using standardised questionnaires. The <3-month period was considered to be of particular interest in the SINPHONIE project because it was similar in length to the air pollution and comfort parameter assessments. Children also underwent clinical tests as described above. Among the

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[3] Myeloperoxidase is an important enzyme used by granulocytes during phagocytic lysis of engulfed foreign particles.
[4] Eosinophil cationic protein (ECP), also known as ribonuclease 3, is a basic protein located in the eosinophil primary matrix and released during the degranulation of eosinophils. This protein is related to inflammation and asthma because in these cases there are increased levels of ECP in the body.
[5] Lysozyme is part of the innate immune system, having several functions. Among the most important, it protects from Gram-positive bacteria. While the skin is a protective barrier due to its dryness and acidity, the conjunctive tissue (eye mucosa) is, instead, protected by secreted enzymes, mainly lysozyme and defensin. When these protective barriers fail, the result is inflammation and irritation.
[6] According to the Nelson's textbook of Pediatrics.

most important was the lung function assessment using spirometry and the test for the fraction of exhaled nitric oxide (FeNO) as a biomarker for inflammation of the airways. In addition, chemical pollutants, biological agents and comfort parameters were quantitatively measured in schools and kindergartens (indoor assessments) and their courtyards (outdoor assessments). The intensity of traffic in the vicinity of the schools and kindergartens was also assessed using a questionnaire.

The three main objectives of the statistical analysis were to: describe the distribution of air pollutants and comfort parameters in schools; estimate the prevalence of health outcomes in children and teachers at these schools; and quantify the associations between exposure to air pollutants in schools and health outcomes in children and teachers at these schools, taking into account the heterogeneity of the countries. Classical statistical methods were used (see details of methods below). For the statistical analyses, SAS 9.0 and STATA/SE 10.0 software were used.

3.9.1 Distribution of chemical, physical and comfort parameters

The distribution of each air pollutant and comfort parameter in the classrooms was plotted, along with the mean, median, standard deviation, minimum value, maximum value and coefficient of variation (CV%) that shows the extent of the variability of the measures in relation to the mean of the sample, as defined by the ratio of the standard deviation σ to the mean μ.

The distribution of air pollutants and comfort parameters in the classrooms was also presented by country. The proportion of children exposed to the median value of air pollutant concentrations was also derived. Pearson's correlation coefficients were used to estimate correlations among air pollutants. The Spearman's test was applied when the distribution of air pollutants was skewed.

3.9.2. Prevalence of health outcomes

The prevalence of health outcomes (symptoms or diseases) was computed in each country as the total number of cases of a symptom or disease in a given population at a specific time. For each health outcome, a pooled prevalence rate was estimated by combining all available prevalence data for each of the countries through meta-analyses using inverse-variance weighting. Between-country heterogeneity was quantitatively assessed by an χ^2-test of heterogeneity.

3.9.3. Associations between environmental exposures and health outcomes

The associations between environmental exposures and health effects were quantified by computing the risk of developing a disease relative to the environmental exposure. This is the ratio of the probability of the event occurring in the exposed group as compared to the non-exposed group.

Risk and 95% confidence interval estimates were provided through the following:

- Mixed-effects logistic regression models, which were fitted (for schoolchildren and teachers) to estimated odds ratios (OR) for binary outcomes for high *vs*. low exposure categories (pollutants, bio-contaminants and ventilation), adjusting for covariates. The hierarchical model had three levels: the first level was children or teachers, the second level was classrooms, and the third level was schools. Countries were grouped into four clusters, which were used as a fixed-effect covariate. The high-exposure category was defined by the part of the distribution being in the worst tertile; otherwise it was defined as low category. Exposure to smoking was used as a categorical variable for adjustment (current, past and never). The models were fitted with Stata software for statistical analysis using the *xtmelogit* function.

- Generalised estimating equations (GEE) models, which were fitted for kindergarten children to estimate robust odds ratios (ORs) for binary outcomes for high *vs*. low exposure categories (pollutants, bio-contaminants and ventilation), adjusting for covariates. The clustered nature of the outcomes was defined by the classrooms (note: as GEE does not allow the fitting of a structure of more than two levels, the school level could not be used in these models). Countries were grouped into four clusters, which were used as a fixed-effect covariate. The high-exposure category was defined by the part of the distribution being in the worst tertile; otherwise it was defined as low category. Exposure to smoking was used as a categorical variable for adjustment (current, past and never). Robust ORs imply that the standard errors were scaled using the square root of deviance-based dispersion. The models were fitted with Stata software for statistical analysis using the *xtgee* function.
- Mixed-effects Poisson models, which were fitted for schoolchildren and kindergarten children to estimate the incident rate ratios (IRR) for stress at school evaluated by a visual analogue scale (VAS) with scores varying from 0 to 10 for high vs. low exposure categories (pollutants, bio-contaminants and ventilation), adjusting for covariates. The hierarchical model had three levels: the first level was children, the second level was classrooms, and the third level was schools. Countries were grouped into four clusters, which were used as a fixed-effect covariate. The high-exposure category was defined by the part of the distribution being in the worst tertile; otherwise it was defined as low category. Exposure to smoking was used as a categorical variable for adjustment (current, past and never). The models were fitted with Stata software for statistical analysis using the *xtmepoisson* function.
- Linear mixed models (LMM), which were fitted to estimate the slopes (β) for predicted lung function tests (LFT) for high vs. low exposure categories (pollutants, bio-contaminants), adjusting for covariates. The hierarchical model had three levels: the first level was children, the second level was classrooms, and the third level was schools. Countries were grouped into four clusters, which were used as a fixed-effect covariate. The models were fitted with MLwiN (and Stata software [*xtmixed* function]) for statistical analysis using RIGLS option (and REML option). Intra-class correlation (ICC) coefficients were computed (not shown), and first-, second- and third-level residuals were checked for the normality assumptions.
- Generalised estimating equations (GEE) models were fitted for schoolchildren and kindergarten children) to estimate robust ORs for the total number of days absent from school for high *vs*. low exposure categories (pollutants, bio-contaminants and ventilation), adjusting for covariates. The clustered nature of the outcomes was defined by the classrooms (note: as GEE does not allow the fitting of a structure of

more than two levels, the school level could not be used in these models). Countries were grouped into four clusters, which were used as a fixed-effect covariate. The high-exposure category was defined by the part of the distribution being in the worst tertile; otherwise it was defined as low category. Exposure to smoking was used as a categorical variable for adjustment (current, past and never). Robust ORs imply that the standard errors were scaled using the square root of deviance-based dispersion. The models were fitted with Stata software for statistical analysis using the *xtnbreg* function.

In these analyses, exposure (independent variable) was categorised into high *vs*. low levels, the former being defined in the worst tertile of the distribution of the air pollutant or comfort parameter, and the dependent variables were dichotomous (presence or absence of symptom/disease) or continuous (lung function and FeNO).

In the graphs presenting RRs, IV stands for inverse-variance weighted and D + L for the Der Simonian – Laird method in the case of random effects). The latter method also provides inverse variance.

In addition, generalised linear mixed models (GLMM) were fitted for schoolchildren and kindergarten children, and teachers to estimate the mean ratios (MR) for continuous outcomes for high *vs*. low exposure categories (pollutants, bio-contaminants and ventilation), adjusting for covariates. The hierarchical model had three levels: the first level was children, the second level was classrooms, and the third level was schools. Countries were grouped into four clusters, which were used as a fixed-effect covariate. The high-exposure category was defined by the part of the distribution being in the worst tertile; otherwise it was defined as low category. Exposure to smoking was used as a categorical variable for adjustment (current, past and never [reference]). The models were fitted with SAS software for statistical analysis using the penalised-quasi likelihood (PQL1) "linearisation-based" (i.e. using first-order Taylor expansion) method with the *glimmix* procedure. Variance components and intra-class correlation (ICC) for pollutants and log-bio-contaminants were computed using LMMs with the following hierarchical design: classrooms (residual error variance) were nested within seasons (heating and non-heating), which were nested within schools, which were further nested within countries. The models were fitted with Stata software for statistical analysis using the *xtmixed* function, which used the REML option for variance components estimation as default in version 12.

3.9.4. Classroom characteristics and children's health

Associations between classroom characteristics and children's health were analysed by logistic regression, where crude and adjusted odds ratios (cOR and aOR) and their 95% confidence intervals (95% CI) were calculated. Adjustments were made for age, gender, maternal education, environmental tobacco smoke and country.

4 Results

4.1 Study population

Overall, 5,175 children (264 or 5.1%, of whom were at kindergartens) and 1,223 teachers coming from 54 cities in 23 European countries participated in the SINPHONIE study, covering a total of 114 primary schools and about 340 classrooms (including kindergarten classrooms), which corresponds to a participation rate of over 70% (out of the 7,061 children present in these classrooms 5,175 (73.3%) had parental approval to participate). Cluster 3 – Central-Eastern Europe has the highest representation in the final SINPHONIE sample, followed by Cluster 4 – Southern Europe, Cluster 2 – Western Europe and Cluster 1 – Northern Europe.

4.2 Characterisation of school buildings based on walkthrough inspections

Information concerning the school building/classroom characteristics that potentially affect IAQ was gathered via walkthrough inspections of the school buildings and selected classrooms, which were carried out during the period October 2011 to March/May 2012. The checklists were completed with no major issues arising from the partners. Each partner entered the collected data into the SINPHONIE database. Two quality control steps were then taken: 1) data cleaning and customisation to obtain datasheets that could be processed in a harmonised way; and 2) data validation (locked cells, ranges for realistic values) to prevent incorrect data being inserted by mistake or as a result of a misunderstanding of data retrieval.

The uploading of building characterisation data to the database on the project website by the country coordinators was finalised for 337 classrooms belonging to 140 buildings of 112 schools in 23 countries. The floor area per school presented quite a high level of diversity, from a Belgian school with an area of 8,657 m^2 and 650 occupants, to a Cypriot school with an area of 300 m^2 and 90 occupants. The school with the highest number of occupants (1,298) was in Serbia.

Some of the results obtained for the school buildings and classrooms were presented according to the sections contained in the checklist. It should be noted that, in some cases, the information presented may show slight differences compared to the information related to school building characterisation obtained, in parallel, through the questionnaires (school, classroom, health) that were completed to capture perceptions regarding IAQ and the health of the school building occupants.

4.2.1 Location of the school

It can be observed that 13% of the school buildings were situated on the sea coast, and the majority of the buildings (71%) inland (Figure 4b). A total of 13% were located in rural areas and 13% in suburban areas with larger gardens, both areas with lower traffic impacts (Figure 4a). The school selection criteria are described in Chapter 3.3 of the present report.

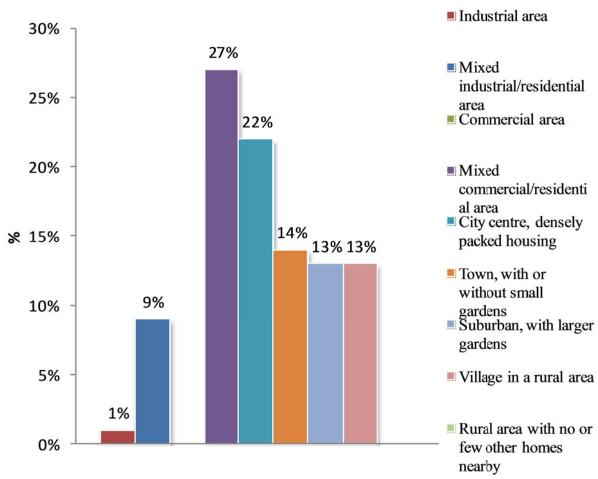


Figure 4a. Type of geographical area

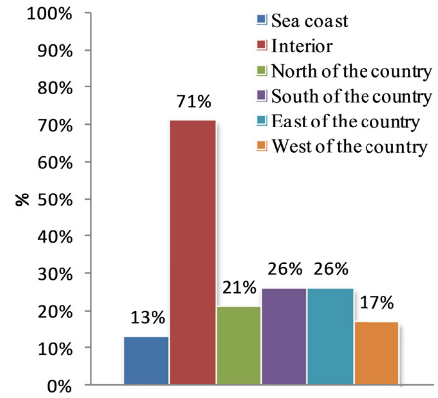


Figure 4b. Geographical location

Concerning potential sources of outdoor air pollution, a very high percentage of school buildings were located near a busy road (67%), although other pollution sources were often identified, such as car parks (46%) and industrial areas (45%) (Figure 5).

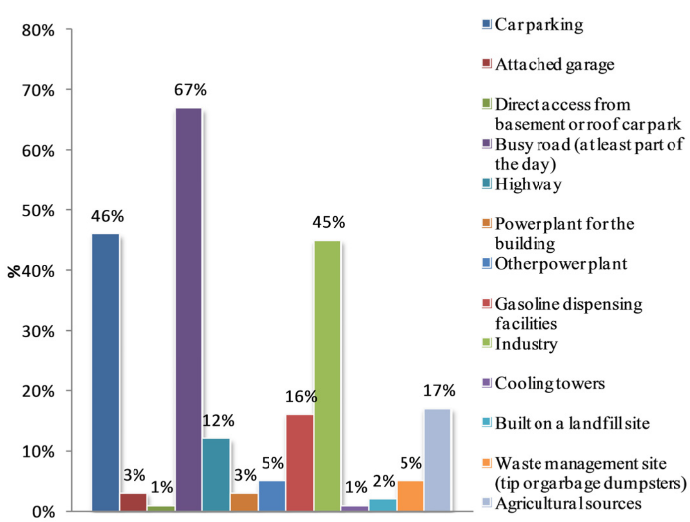


Figure 5. Potential sources of outdoor air pollution near school buildings

Many noise sources were also identified, with 58% of the school buildings exposed to noise from busy roads. Surprisingly, some public buildings, such as halls and churches, were presented as constituting noise sources for 20% of the school buildings (Figure 6). Of course, these factors reflect the structure and development of the settlements.

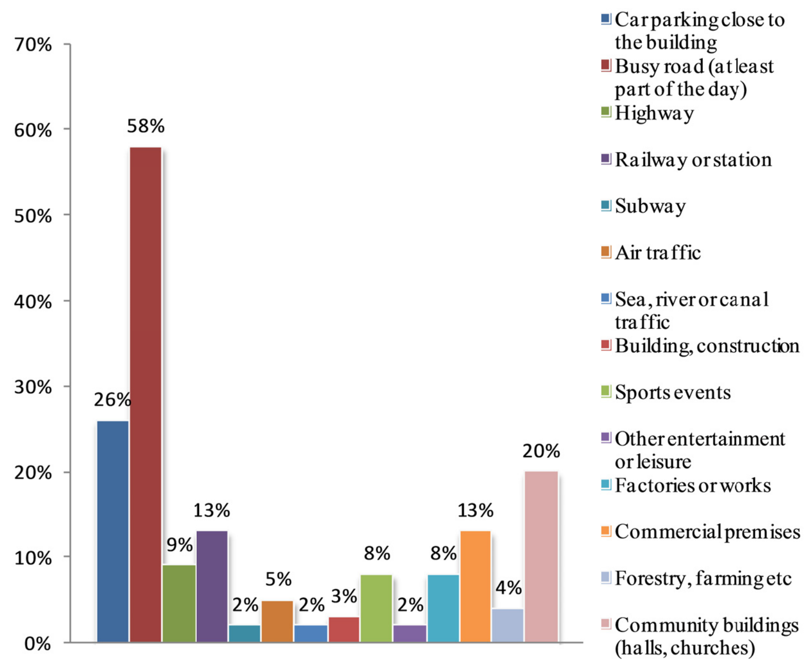


Figure 6. Noise sources outside school buildings

4.2.2 Construction characteristics

More than half of the schools (61%) were built between 1950 and 2000. Only 9% of the schools were built after 2000, and 11% were constructed even before 1900 (Figure 7). It should also be noted that 90% of the buildings were built originally as schools, and 59% of the buildings were converted into schools or were refurbished following their construction.

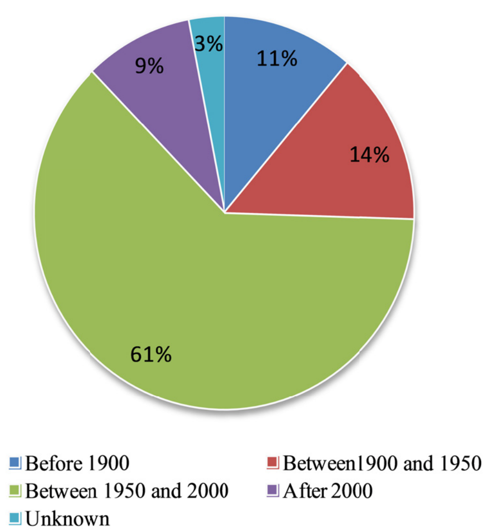


Figure 7. Year of construction

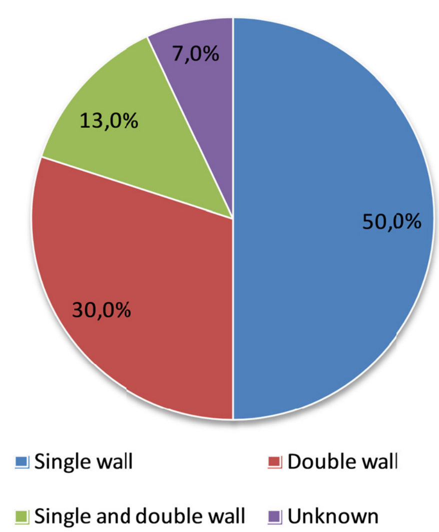


Figure 8. Type of external walls

Figure 8 shows that 50% of the school buildings had only single walls, while 30% featured double walls. However, 83% of the walls were massive, while only 2% were of lightweight construction (Figure 9). Similarly, in 70% of the school buildings the roof had a massive structure. Concerning insulation, 61% of the schools did not have wall insulation and 42% did not have roof insulation. Detailed data on the type of insulation material and thicknesses were only obtained for a few school buildings. Concerning the roofs of the school buildings, 55% of the buildings had a flat roof and 45% a ridge roof.

Concerning the type of foundation/ground floor, 45% of the schools had a basement, 37% a slab on grade and 6% a crawl space, as shown in Figures 9 and 10.

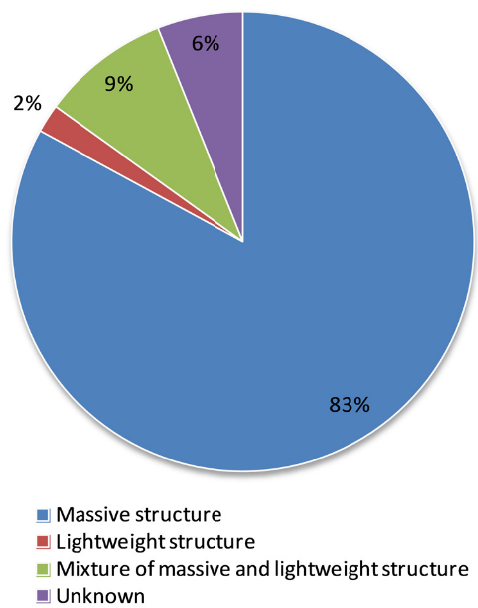


Figure 9. Type of construction of external walls

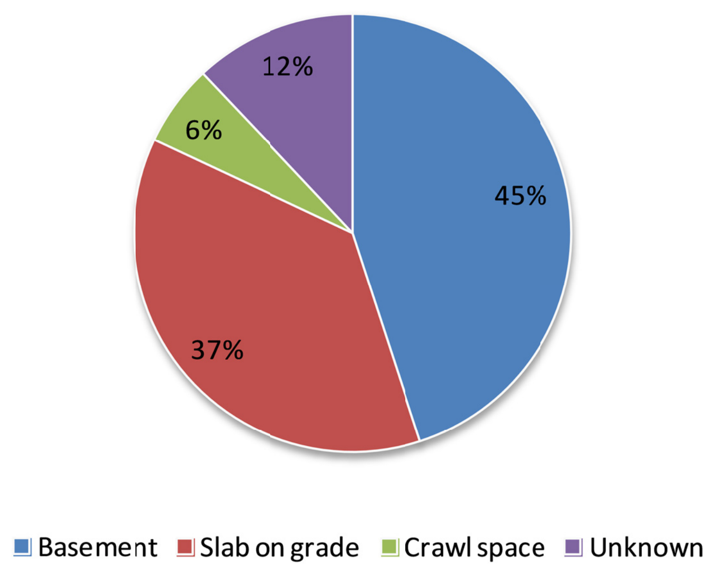


Figure 10. Type of foundation/ground floor

It was observed that 73% of the schools were located in a low-radon zone. However, 23% of schools did not report this information, and according to the current study only 4% of the schools are known to be located in a radon risk zone.

The proportion of school buildings with certification under national legislation (such as Building Research Establishment Environmental Assessment Methodology (BREEAM) [130], etc.) was 17%.

4.2.3 Ventilation

The percentage of school buildings with natural ventilation was 86%, while 7% had mechanical ventilation and 7% natural assisted exhaustion (Figure 11). In schools with mechanical ventilation and natural assisted exhaustion, the ventilation was CO_2 controlled in 47% of cases (Figure 12).

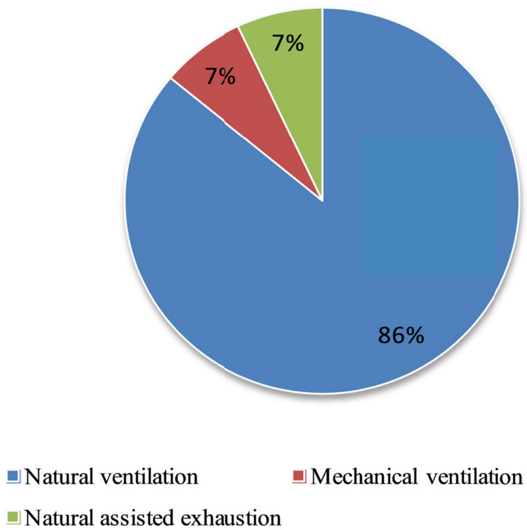


Figure 11. Type of ventilation strategy

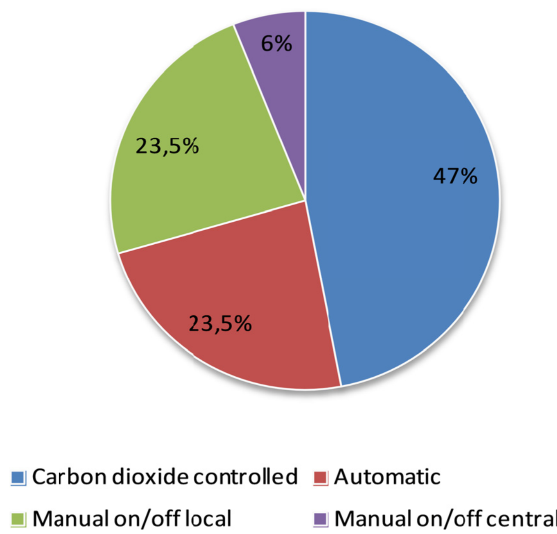


Figure 12. Type of control of mechanical ventilation or natural assisted exhaustion

4.2.4 Past occurrences or visible problems

The fairly high percentage (46%) of visible problems observed and reported during the inspection is of relevance. In 25% of the school buildings there were visible air leaks in the structure. In terms of water leakages or flooding that had occurred recently (in the last 12 months), 21% of reported problems were located on the roof and 7% in water pipes. Only one school reported fire damage.

4.2.5 Indoor air pollution sources

It was found that 5% of schools still had a room for use by smokers. These schools were all located in Central-Eastern European countries. It was also found that 95% of the school buildings had a kitchen, and 85% of the schools had a cleaning schedule for the communal parts of the building. Regarding the use of pesticides in the last 12 months, a higher number of schools were found to use pesticides indoors than outdoors. Most of the pesticides used indoors in the last 12 months were to eliminate mice and rats, and only 16% of schools used pesticides against ants (Figure 13).

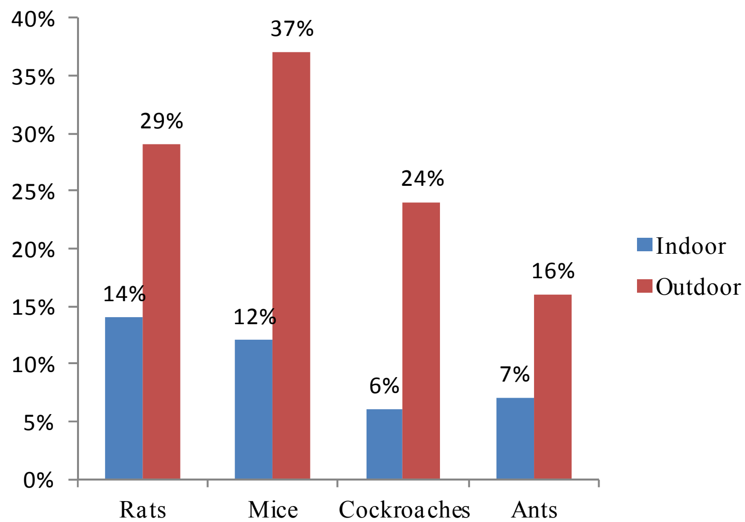


Figure 13. Use of pesticides in the last 12 months

4.2.6 Classroom characterisation

As stated above, 337 classrooms were inspected and some of the statistics are presented in Table 12.

Table 12. Characterisation of classrooms

Characteristics	
Floor area (m^2)*	55 (24–135)
Ceiling height (m)*	3.3 (2.5–5.3)
Total number of children	7,061
Asbestos sealed (%)	1
Exposure to asbestos (%)	1
Lead in water pipes (%)	1
Main type of wall covering	
Paint (%)	80

* mean (range)

The mean occupation density (m^2/child) for the entire range of classrooms was 2.44 (with a maximum of 6.15 for an Italian school and a minimum of 0.83 for an Albanian school). In 8% of the classrooms, the occupation density was lower than 1.5 m^2/per child (Figure 14). However, when compared against the criteria of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [4] (2.0 m^2/child), the proportion of classrooms below the recommended value rises to 23%.

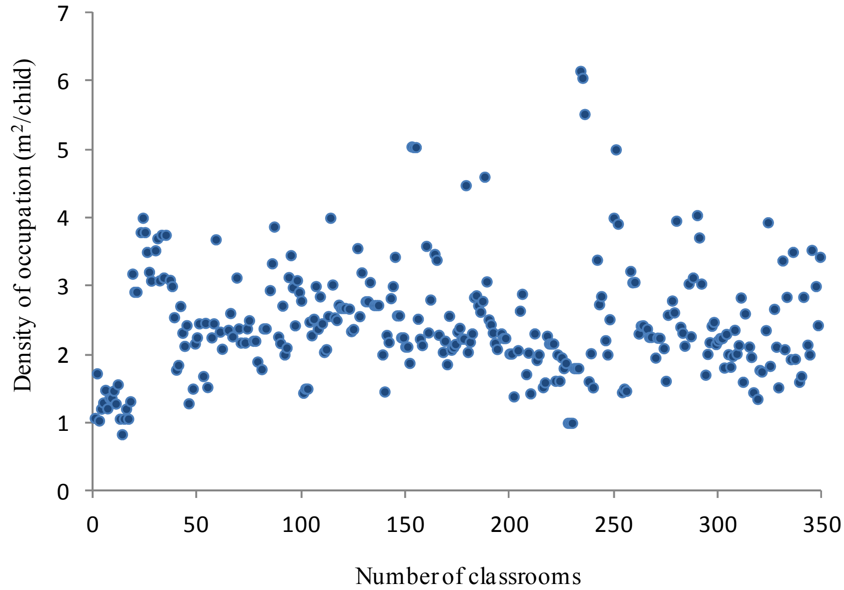


Figure 14. Occupation density per classroom

As shown in Figure 15, 21% of the schools still had single-glazed windows. This may not represent a significant problem if the windows are in façades oriented towards the south in countries belonging to SINPHONIE Cluster 4.

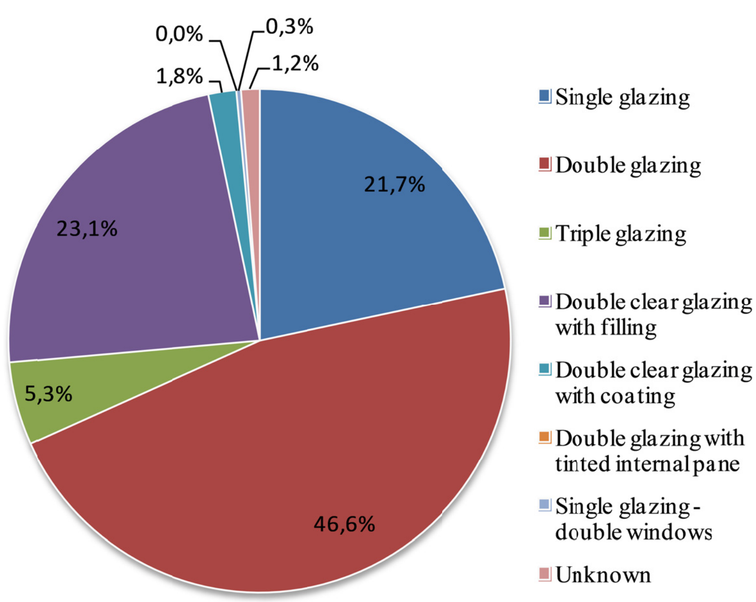


Figure 15. Type of window glazing in school buildings

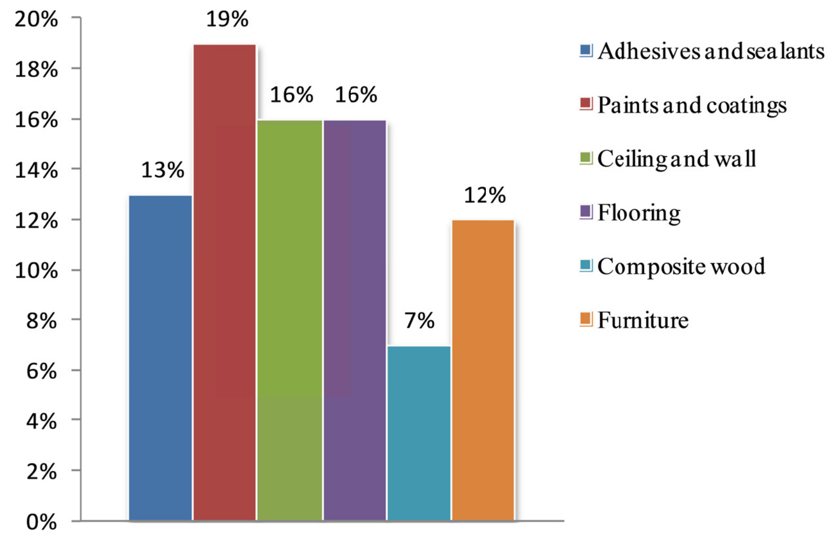


Figure 16. Low-emission building materials in school buildings

Figure 16. shows that a rather low percentage of low-emission materials are used in European schools. Paint was the most commonly used ceiling material, followed by concrete and gypsum or plaster (Figure 17). With respect to flooring, 34% of the classrooms had a synthetic smooth surface (PVC, vinyl, linoleum) followed by stone or ceramic tiles and wood or cork, and 6% of the classrooms had carpets (Figure 18).

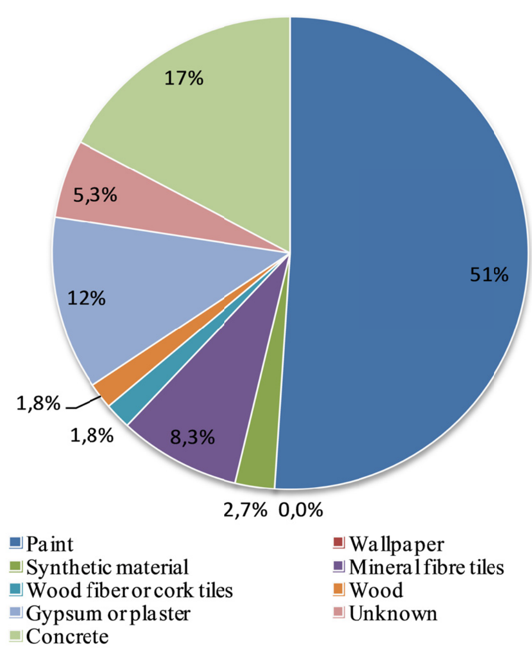


Figure 17. Main type of ceiling surface

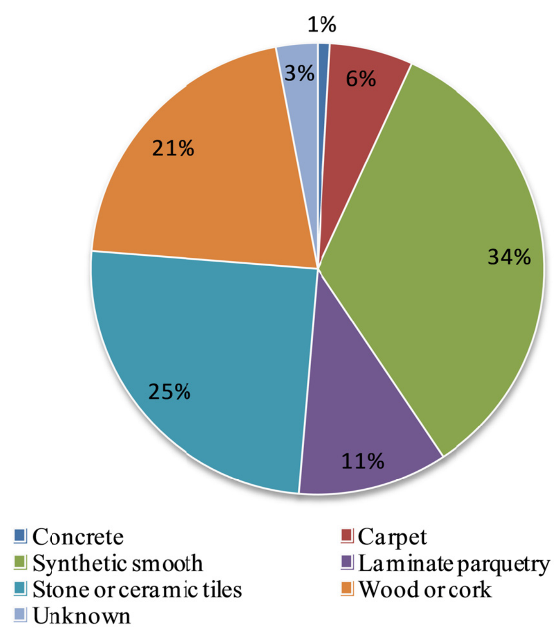


Figure 18. Main type of floor covering

4.2.7 Visible problems in classrooms

In 7% of classrooms there was visible mould growth on the walls and ceilings, in the corner of the ceiling, and on the window frames (Figure 19). In 17% of the classrooms there was a tendency towards the formation of condensation inside the windows, and in 9% a tendency towards condensation on the window frames.

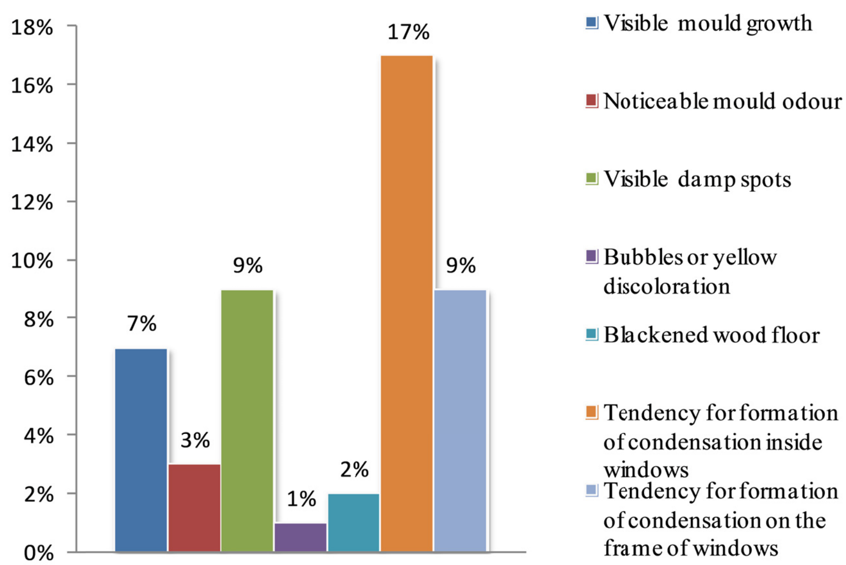


Figure 19. Visible problems in classrooms

4.2.8 Heating and ventilation

Most of the schools (92%) had a heating system. In 59% of schools the system was exclusively for heating, and in 33% of schools it provided heating plus hot water. No heating system was reported in 3% of the classrooms (Figure 20).

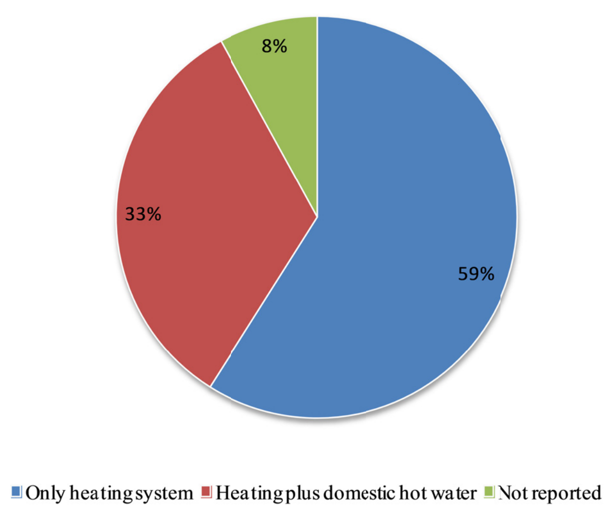


Figure 20. Heating systems in school buildings

4.2.9 Use of natural ventilation

Most of the classrooms (90%) had opening windows, while 2% had another mode of natural ventilation and 7% had a hybrid/mixed mode of ventilation. In 88% of the schools the window opening period was during the breaks, and in 70% it was during teaching hours (Figure 21). It should be noted that natural ventilation by window opening may interfere with other environmental quality parameters such as thermal comfort, noise, drafts, outdoor pollution, etc., with the impact on classroom occupants being greater if the windows are opened during teaching hours.

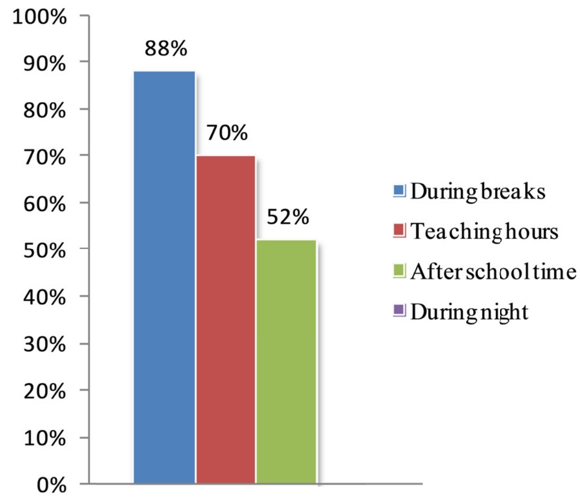


Figure 21. Timing of window opening in school buildings (during the night the windows were closed)

4.2.10 Indoor air quality sources associated with the use of consumer products

The use of chalk on a blackboard was very dominant in the schools (63%). Markers were used in 18% of the schools, and electronic and interactive boards were used in 11% of schools (Figure 22).

It is particularly relevant that 46% of the classrooms contained one or more computer, printer or photocopier, to a maximum of five. Air fresheners were used in permanent mode in only 1% of classrooms, and occasionally in 4%. Observations related to type of furniture used and cleaning activities in school buildings are presented in Figures 23 and 24 respectively.

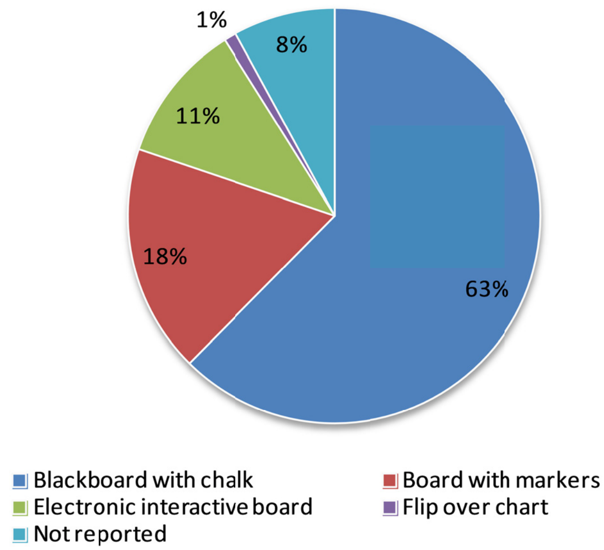


Figure 22. Type of board used in the classroom

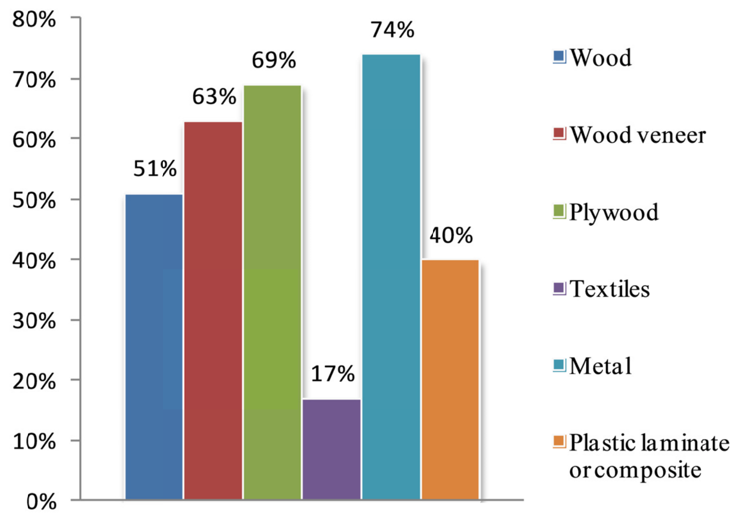


Figure 23. Type of furniture in school buildings

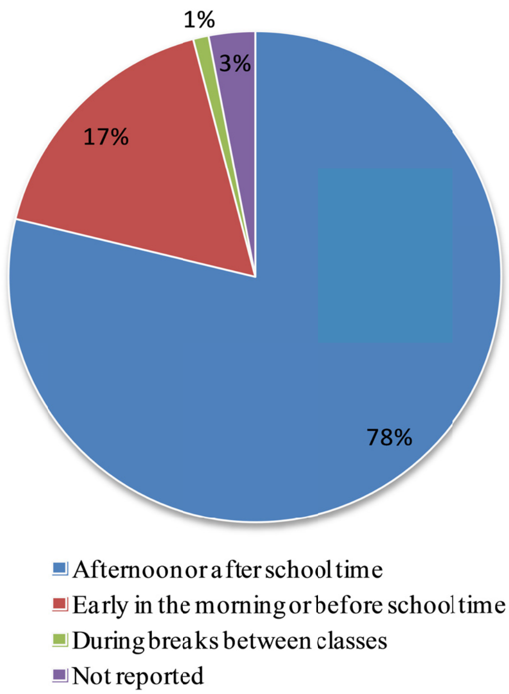


Figure 24. Cleaning schedule in school buildings

In conclusion, from the characterisation of SINPHONIE school buildings and classrooms, certain parameters emerge as being potentially relevant to IAQ-related health effects among schoolchildren and staff. These are presented in Table 13, according to the four SINPHONIE clusters. The selected schools in SINPHONIE can be considered as representative of the building stock in each country. Concerning the analysis and interpretation of the biological measurements performed within SINPHONIE, it is important to note that 25% of the schools presented air leaks in their structure and 7% of the classrooms had visible mould growth.

Concerning the analysis of results related to some of the chemical pollutants (VOCs and aldehydes), it is important to bear in mind that 46% of classrooms contained one or more computer, printer or photocopier; a high percentage of composite wood was present in furniture; and a very small percentage of classrooms featured certified low-emission building materials. In the case of particulate matter results, it is important to bear in mind that in 63% of the classrooms blackboards with chalk were used. Surprisingly, in 5% of investigated schools there was still a room set aside for smokers.

Table 13. Characteristics of school buildings and classrooms by SINPHONIE cluster

	All data (N=112)	Cluster 1 Northern Europe (N=14)		Cluster 2 Western Europe (N=26)		Cluster 3 Central-Eastern Europe (N=41)		Cluster 4 Southern Europe (N=31)	
	%								
		Relatively to the total	*Relatively to the cluster*	Relatively to the total	*Relatively to the cluster*	Relatively to the total	*Relatively to the cluster*	Relatively to the total	*Relatively to the cluster*
Schools near a busy road	67.1	4.5	36.0	16.1	69.4	28.6	78.1	17.9	64.7
Schools near industry	44.6	2.7	21.6	11.6	50.0	16.1	44.0	14.3	51.7
Schools located in low-radon zone	72.5	6.7	53.6	22.5	96.9	25.0	68.3	18.0	65.0
Schools with a yard	96.9	12.4	99.2	22.3	96.1	36.6	99.1	25.6	92.5
Schools built originally for use as schools	89.7	10.3	82.4	20.6	88.7	34.9	95.3	23.8	86.0
Schools without wall insulation	61.2	2.5	20.0	9.9	42.6	27.3	74.6	21.5	77.7
Schools without roof insulation	42.1	1.7	13.6	5.0	21.5	21.5	58.7	14.0	50.6
Classrooms with low-emission building materials									
Adhesives and sealants	12.8	0	0	3.9	16.8	8.0	21.9	0.9	3.3
Paints and coatings	19.0	2.7	21.6	5.3	22.8	8.3	22.7	2.7	9.8
Ceiling and walls	15.7	0	0	6.2	26.7	7.4	20.2	2.1	7.6
Flooring	15.7	0	0	2.1	9.0	7.7	21.0	5.9	21.3
Composite wood	6.5	0	0	0.9	3.9	5.3	14.5	0.3	1.1
Furniture	11.6	0	0	1.8	7.8	7.1	19.4	2.7	9.8
Classrooms where the floor area per child is < $1.5m^2$	8.2	0.3	2.4	0	0	1.2	3.3	6.6	23.8
Schools with natural ventilation	86.0	4.1	32.8	20.7	89.2	35.5	97.0	25.6	92.5

4.3 Indoor air pollutants and exposure in classrooms

The levels of chemical air pollutants, bio-contaminants and comfort parameters assessed *in situ* varied within classrooms and kindergartens in the countries.

4.3.1 Chemical, physical and comfort parameters

Observed levels

Overall, children in primary schools were not excessively exposed to chemical air pollutants, if we consider the mean and median concentration levels. However, the maximal concentration values for air pollutants (with the exception of $PM_{2.5}$) observed in 1 to 4% of the classrooms were always higher than the WHO air quality guideline values (Table 14). Concentrations of $PM_{2.5}$ higher than 25 µg/m^3 were found in 65% of the classrooms.

Table 14. Distribution of chemical, physical and comfort parameters in primary schools and comparisons with existing guidelines (N=300)

Parameter	WHO guidelines [125] [EU-INDEX] [70] [French ANSES] [1] [Maximum allowable concentration Netherlands] [112] [Guideline value Flemish Indoor Decree] [21]		Mean	Median	Min-Max	SD
	Short-term	Long-term				
Formaldehyde[1]	100 [30] [50] [120]	100 [10] [10] [10]	15	12	1.0 - 66	11
Benzene[1]	-	no safe level [10 [20] [10]	4	2	DL - 38	6
Naphthalene[1]	-	10	2	DL	DL - 31	8
Limonene[1]	[20]	[450]	38	9	DL - 672	133
NO_2[1]	200 [200]	40 [40] [135]	14	11	DL - 88	9
$PM_{2.5}$[1]	25	10 [10] [15]	44	37	4 - 250	37
Ozone[1]	100 (outdoors)	-	8	3	DL - 142	4
CO[7]	100* [100]* [30]*	-	1	DL	DL - 122	1
T3CE[1]	-	23**	3	DL	DL - 126	8
T4CE[1]	-	250	1	DL	DL - 81	2
Radon[3]	-	167***	205	101	DL - 9190	2146
Relative humidity[4]	-	50****	43	42	6 - 98	12
Temperature[5]	-	-	20	21	-8 - 30	2
CO_2[7]	-	1000 [492]	1433	1257	269 - 4960	856
Ventilation rate[6]	-	-	1	0	0 – 4	1

Min: minimum; Max: maximum; SD: standard deviation; T3CE: trichloroethylene; T4CE: tetrachloroethylene; DL: detection limit

[1]µg/m^3; [3]Bq/m^3; [4]%; [5]°C; [6] /hr, [7]ppm (parts per million)

*15 minutes; **lifetime exposure with acceptable risk at 10^{-5}; ***concentration associated with an excess lifetime risk of 1 per 1,000 (non-smokers); ****by increasing the relative humidity to above 50% within 20–25°C, 80% or more of all averagely dressed individuals would feel comfortable (US-EPA).

Lower maximal values, although still higher than existing guideline values, were observed in kindergartens (Table 16). It should be noted, however, that the group size in the kindergartens (N=25) is far smaller than the primary school group size (N=300).

Distribution of chemical air pollutants and comfort parameters in primary schools where teachers participated (N=106) and comparisons with existing guidelines are shown in Table 16.

Table 15. Distribution of chemical, physical and comfort parameters in kindergartens (N=25) and comparisons with existing guideline values

Parameters	WHO guidelines [125] [EU-INDEX] [70] [French ANSES] [1] [Maximum allowable concentration Netherlands] [112] [Guideline value Flemish Indoor Decree] [21]		Mean	Median	Min - Max	SD
	Short-term	Long-term				
Formaldehyde[1]	100 [30] [50]	100 [10] [10] [10]	15	13	6 - 38	10
Benzene[1]	[120]	no safe level [10 [20] [10]	4	3	1 - 21	6
Naphthalene[1]	-	10	3	DL	DL - 15	5
Limonene[1]	-	[450]	44	21	DL - 330	70
NO_2[1]	[20]	40 [40] [135]	16	13	5 - 32	10
$PM_{2.5}$[1]	200 [200]	10 [10] [15]	56	46	14 - 163	34
Ozone[1]	25	-	6	6	DL - 16	15
CO [7]	100 (outdoors)	-	0	DL	DL - 2	6
T3CE[1]	100* [100]* [30]*	23**	3	DL	DL -21	26
T4CE[1]	-	250	1	DL	DL - 6	5
Radon[3]	-	167***	579	68	32 - 9850	648
Relative humidity[4]	-	50****	45	43	23 - 80	14
Temperature[5]	-	-	21	21	14 - 24	4
CO_2[7]	-	1000 [492]	1309	1065	394 - 3530	892
Ventilation rate[6]	-	-	1	0	0 - 4	1

Min: minimum; Max: maximum; SD.: standard deviation ; T3CE: trichloroethylene; T4CE: tetrachloroethylene; DL: detection limit

[1]µg/m^3; [3] Bq/m^3; [4] %; [5] °C; [6] /hr, [7] ppm (parts per million);

*15 minutes; **lifetime exposure with acceptable risk at 10-5; ***concentration associated with an excess lifetime risk of 1 per 1,000 (non-smokers); ****by increasing the relative humidity to above 50% within 20-25°C, 80% or more of all averagely dressed individuals would feel comfortable (US-EPA).

Comparison with (indoor) air quality guidelines

The highest weekly mean benzene concentration was 38 µg/m³, and a maximum formaldehyde concentration of 66 µg/m³ was measured indoors, the latter exceeding the corresponding guideline value of the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) more than six times. The maximal registered weekly mean NO_2 concentration of 88 µg/m³ was twice as high as the WHO guideline value (40 µg/m³). Although very low median and mean values were detected for trichloroethylene (T3CE) and tetrachloroethylene (T4CE) in kindergartens and primary schools, the maximum concentrations for these two chemicals in primary schools exceeded the WHO guidelines considerably.

In terms of mean values, WHO recommended values (for pollutants for which these exist) were not complied with in the monitored kindergartens and schools for $PM_{2.5}$ and radon. The median value (which denotes the concentration level to which 50% of individuals are exposed) was always lower than the mean. However, the median values were above the recommended levels in the case of formaldehyde and fine particles.

A large degree of heterogeneity between and within the countries was observed in the distribution of chemical air pollutants in schools and kindergartens (see Figure 25 and Figure 26, in which the boxes represent the 25th percentile, the median and the 75th percentile; the small quadrangles indicate mean values; and the extended lines the range of the minimum to maximum values measured in each classroom per country).

Table 16. Distribution of chemical air pollutants and comfort parameters in primary schools where teachers participated (N=106) and comparisons with existing guidelines

Parameters	WHO guidelines [125] [EU-INDEX] [70] [French ANSES] [1] [Maximum allowable concentration Netherlands] [112] [Guideline value Flemish Indoor Decree] [21]		Mean	Median	Min-Max	SD
	Short-term	Long-term				
Formaldehyde[1]	100 [30] [50]	100 [10] [10] [10]	15	13	4 - 46	10
Benzene[1]	[120]	no safe level [10 [20] [10]	4	2	DL - 24	5
Naphthalene[1]	-	10	2	DL	DL - 27	7
Limonene[1]	-	[450]	38	11	DL – 511	125
NO_2[1]	[20]	40 [40] [135]	14	12	1 - 60	8
$PM_{2.5}$[1]	200 [200]	10 [10] [15]	43	37	4 - 185	33
Ozone[1]	25	-	8	4	DL - 133	4
CO [7]	100 (outdoors)	-	1	DL	DL - 42	1
T3CE[1]	100* [100]*	23**	3	DL	DL - 85	6
T4CE[1]	[30]*	250	1	DL	DL - 31	2
Radon[3]	-	167***	231	99	DL - 7610	1880
Relative	-	50****	43	41	7 - 73	10
humidity[4]	-	-	20	21	8 - 25	2
Temperature[5]	-	1000 [492]	1414	1311	364 - 4130	530
CO_2[7]	-	-	1	0	0 – 3	1
Ventilation rate[6]						

Min: minimum; Max: maximum; SD : standard deviation ; T3CE: trichloroethylene; T4CE: tetrachloroethylene; [1] $\mu g/m^3$; [2] ppm (parts per million); [3] Bq/m^3; [4]%; [5] °C; [6] /hr, [7] ppm (parts per million);
*15 minutes; **lifetime exposure with acceptable risk at 10-5; ***concentration associated with an excess lifetime risk of 1 per 1,000 (non-smokers); ****by increasing the relative humidity to above 50% within 20-25°C, 80% or more of all averagely dressed individuals would feel comfortable (US-EPA).

In most countries, both the short-term and long-term WHO limits for $PM_{2.5}$ were exceeded by the measured mean concentrations during teaching time. In 12 out of the 23 countries, the observed mean concentration values for formaldehyde were higher than the ANSES guideline value. Three countries presented mean benzene concentrations higher than the recommended WHO limits, but only one presented mean levels higher than the recommended limits for naphthalene and limonene. Both the NO_2 and ozone concentration limit values were respected. The most abundant detected VOC was limonene.

Measurements of formaldehyde in the indoor air in schools have rarely been published in peer-reviewed journals. Only 12 studies out of the 45 identified in the review carried out in the framework of the SINPHONIE study included this air pollutant. However, an interview among SINPHONIE partners led to the identification of 27 IAQ studies performed in schools in EU member states since 2005 that report indoor formaldehyde levels. Formaldehyde exposure has been measured using different methods. Smedje et al. [102], Norbäck et al. [82] and Kim et al. [65] used glass-fibre filters with a pump, and Marks et al. [73], Zhao et al. [127] and Annesi-Maesano et al. [3] a passive method. The sampling time when using passive air sampling varied according to the type of passive sampling device used: a five-day period in the case of Annesi-Maesano et al. [3], a seven-day period in the case of Zhao et al. [127], or two days during six weeks in the study by Marks et al [73]. Mean concentrations varied between 7 µg/m^3 and 9 µg/m^3 for Kim et al. [65], Mi et al. [77], Smedje et al. [102], Norbäck et al. [81] and Csobod et al. [20]. The study by Marks et al. [73] showed concentrations higher than the others, with a mean concentration of 35.1 µg/m^3. Zhao et al. [127] found a mean concentration of 2.8 µg/m^3. Smedje et al. [102] and Norbäck et al. [81] do not give precise results, although formaldehyde concentrations were under 5 µg/m^3 and 10 µg/m^3 respectively. Lastly, Annesi-Maesano at al. [3] found that the formaldehyde concentration ranged between 12 µg/m^3 and 56 µg/m^3 in a large sample of classrooms in their six-city study.

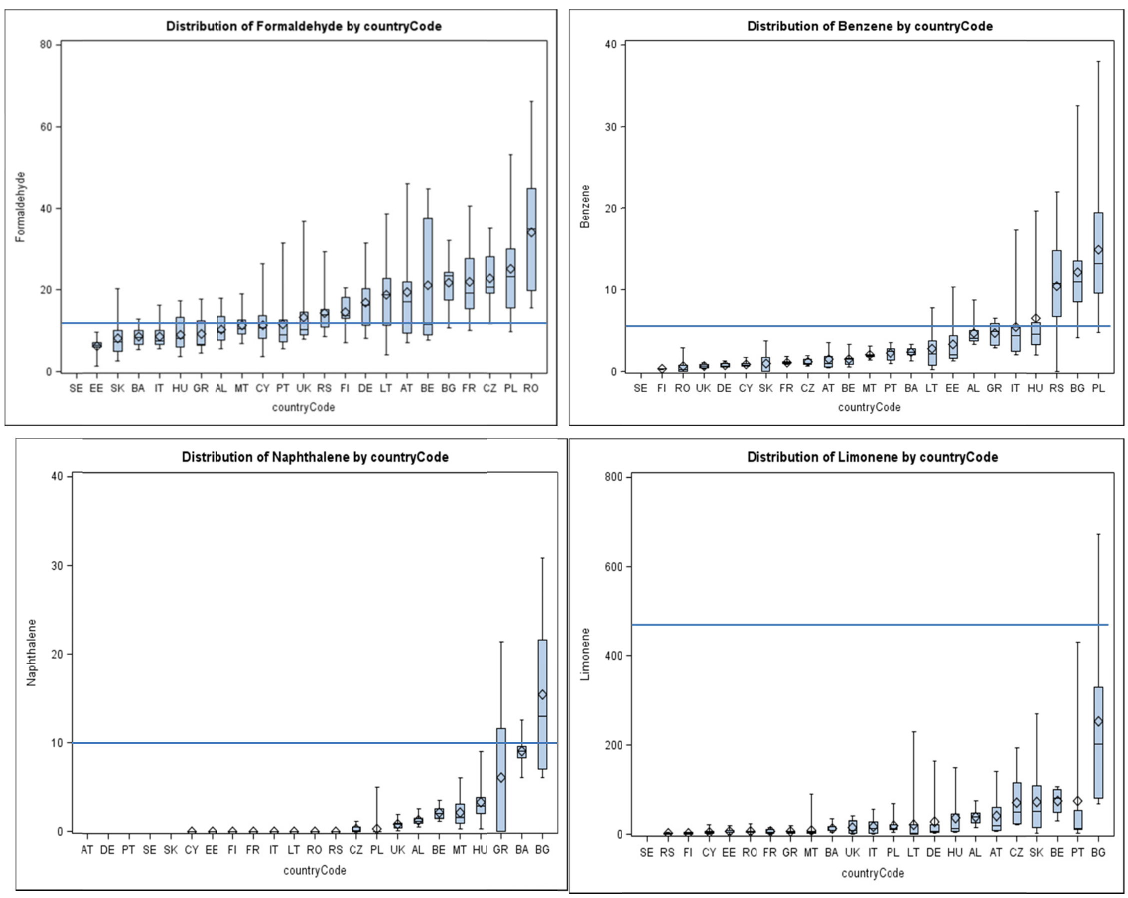


Figure 25. Distribution of indoor concentrations of formaldehyde, benzene, naphthalene and limonene by country code

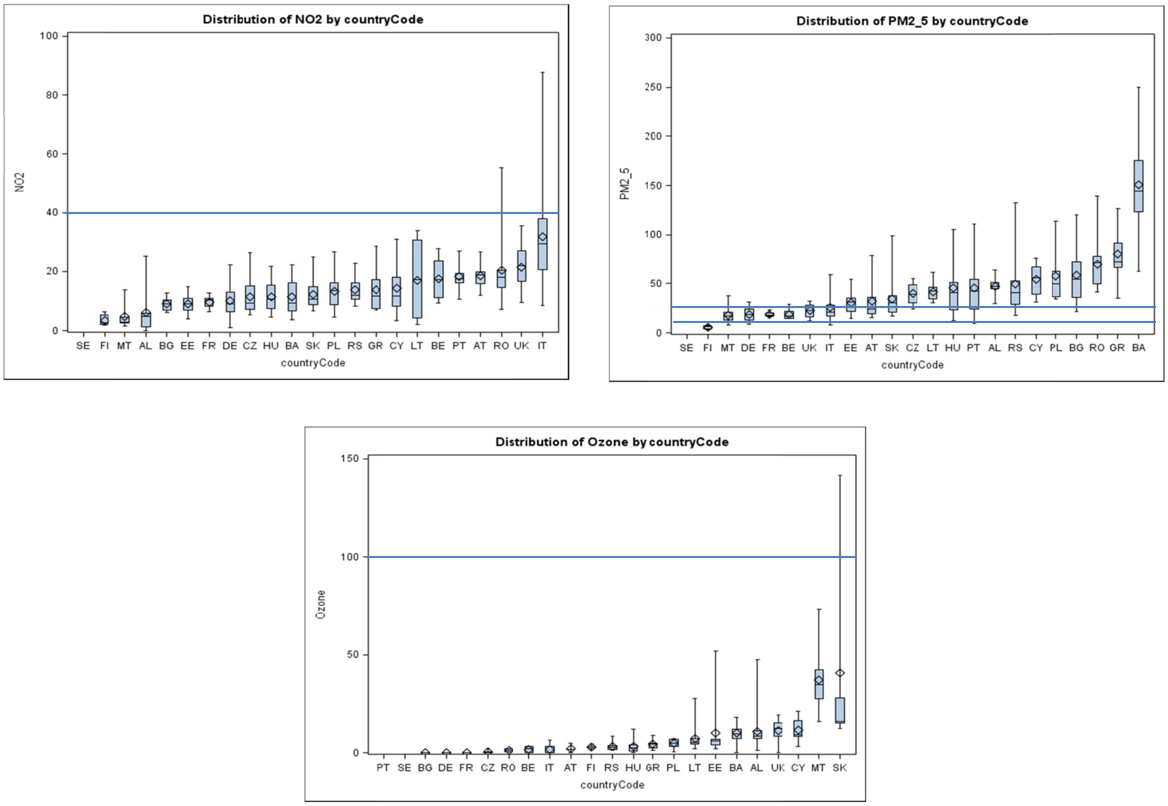


Figure 26. Distribution of indoor concentrations of NO_2, $PM_{2.5}$ and ozone by country code

Classroom benzene levels ranging from 0.14 to 3.08 µg/m³ were published by Stranger et al. [106]. Additional indoor benzene measurements have been performed in at least 25 other IAQ studies in schools in different EU countries. Although not reported in peer-reviewed publications, indoor T3CE and T4CE have been assessed in at least eight studies organised in German, Belgian, French, Austrian, Czech and Portuguese schools since 2005. Reported indoor levels in Belgian schools, for example, did not exceed the detection limit of 0.1 µg/m³ for T3CE, and ranged from 0.1 to 2.16 µg/m³ for T4CE [99]. Indoor limonene was measured in 12 studies in eight different EU countries participating in SINPHONIE. Weekly mean concentrations ranging from 0.5 to 20 µg/m³ were measured in 27 Belgian classrooms [106]). Naphthalene has been measured in limited studies in a few countries, but no results have been published.

In the open literature, NO_2 concentrations measured indoors in schools were not much higher than those found outdoors. Nitrogen dioxide in classrooms is principally assessed using passive diffusion samplers [2, 3, 73, 77, 81, 111] over five to seven days, or by chemiluminescence [2, 15, 95]. Maximum indoor concentrations were reported in a study by Castro et al. [13], with a mean of 92.5 µg/m^3; and in a study by Stranger et al. [105], with a mean of 115 µg/m³ (in schools at urban hotspot locations in summer). Minimum concentrations of NO_2 were reported in a study by Smedje et al. [104], with a median of 5 µg/m^3. Outdoor maximum and minimum NO_2 concentrations were reported to be 63 µg/m^3

(mean concentration, Mi et al. [77]) and 19 μg/m^3 (median concentration in the schoolyard, Annesi-Maesano et al. [2]) respectively.

Few studies have assessed fine particles ($PM_{2.5}$) in schools. Exposure to $PM_{2.5}$ has been assessed using a dispersion model in the vicinity of schools [70], with pumps in the schoolyards [2] and in classrooms [3], and with a dust track aerosol monitor in classrooms [128]. In Annesi-Maesano et al. [2, 3], the five-day mean levels of $PM_{2.5}$ were taken into account. In Zuraimi et al. [128], exposure was assessed from 8 a.m. to 5 p.m. at one-minute intervals. In both studies, schoolchildren were found to be highly exposed.

Ozone in schools has been measured using different techniques: UV absorption [15, 123], passive diffusion samplers during seven [74, 126] or five [7] days, and chemiluminescence [94]. In most studies, ozone concentrations were higher outdoors than indoors. The study by Mi et al. [77], which measured this pollutant both outdoors and indoors, found an outdoor mean concentration four times higher than the indoor mean concentration (20.9 μg/m^3 compared to 5.3 μg/m^3). By contrast, Zhao et al. [127] did not find much difference between indoor and outdoor concentrations (10.1 μg/m^3 compared to 12.4 μg/m^3).

Carbon monoxide in schools has been measured using different methods: non-disperse infrared absorption [15], a monitoring station in the city, and a CO measurer [13, 126]. Carbon monoxide has been little measured in schools. Maximum concentrations were quite similar (3 ppm) in the studies carried out by Chen et al. [15] and Castro et al. [13]. No associations were found between CO exposure and respiratory health.

4.3.2 Comfort parameters

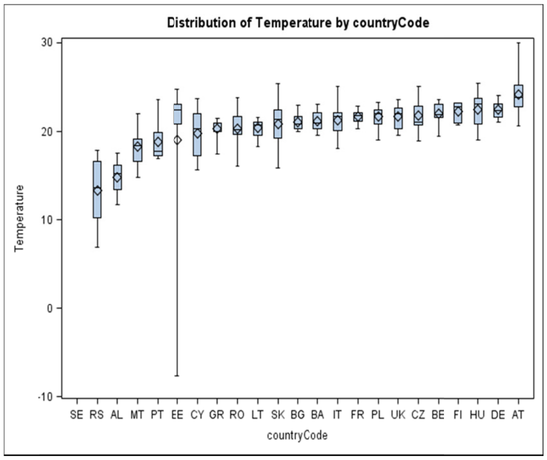
Observed levels

Large variations have been observed among and within countries in terms of temperature, relative humidity and CO_2, as expected due to the climatic differences (Figures 27 and 28).

In the literature, temperature has been assessed in classrooms using direct reading instruments (Q-track) [66, 75], Assman monitors [35, 60, 61, 3], and battery-operated data loggers with internal sensors [71, 126]. Temperature was generally higher indoors than outdoors. Varying temperature values and a maximum temperature of 29.5°C were observed in Zuraimi et al. [128] in the case of a hybrid ventilation system. The minimum indoor temperature was 14.7°C. Other indoor temperatures were between 20 and 25 °C.

Relative humidity has been measured in most studies using the same devices as for temperature. An ideal relative humidity in the indoor environment is between 30 and 70% [14], and most of the studies found relative humidity within this interval. However, some studies found excessive percentages (e.g. Castro et al. [13] and Zuraimi et al., in the case of a hybrid ventilation system [128]).

In the SINPHONIE campaigns, CO_2 exposure ranged from 269 ppm to 4,957 ppm among schoolchildren, the mean being 1,433 ppm and the median 1,257 ppm. Similar trends towards large variations were seen among children at kindergartens and teachers, the median values in these groups being 1,065 ppm (children at kindergartens) and 1,311 ppm (teachers). Overall, half of all children and teachers were exposed to values higher than those recommended for CO_2. The overall median was 1,257 ppm, far higher than the 1,000 ppm recommended value (Figure 29). Lastly, very low ventilation rates were observed. In all cases the coefficients of variation (%) were elevated (Figure 30).



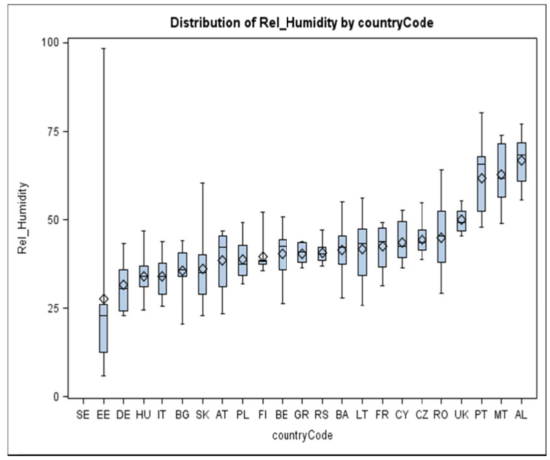
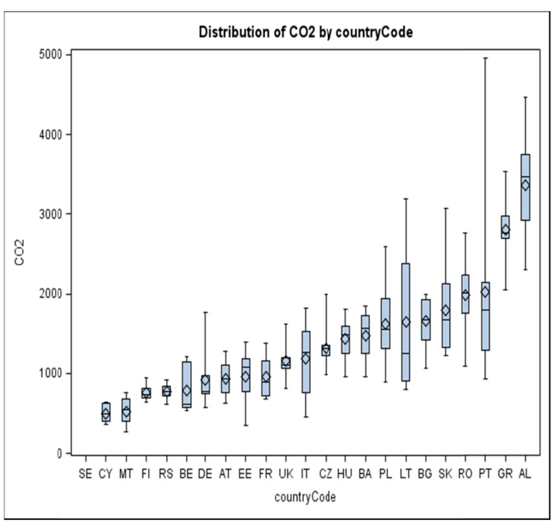


Figure 27. Distribution of temperature by country

Figure 28. Distribution of relative humidity by country

Carbon dioxide has been measured using direct reading instruments in various school surveys reported in the literature. Exposure times have varied: one hour for indoor measurements in Zhao et al. [126] during classroom occupancy; three 15-minute periods in the study reported by Smedje et al. [102] and Norbäck et al. [82, 83]; at the end of lessons during one week at one-minute intervals in Fraga et al. [36]; and during one day in the HESE study conducted in five European countries [43].



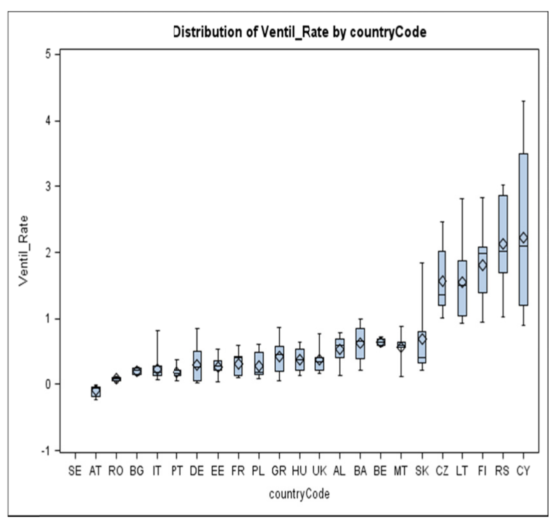


Figure 29. Distribution of CO_2 by country

Figure 30. Distribution of ventilation rate by country

In most studies, CO_2 concentrations (median or mean values) exceeded 1,000 ppm, which is the recommended guideline value for good IAQ. Kim et al. [65,] and Smedje et al. [102] found concentrations below this limit value. Simoni et al. [98], in the HESE study, found a median value of 1,490 ppm. Only in Norway and Sweden were the median concentrations below 1,000 ppm (686 ppm and 657 ppm, respectively).

The results for temperature and relative humidity according to the SINPHONIE clusters are presented in Figure 31 for all the classrooms studied.

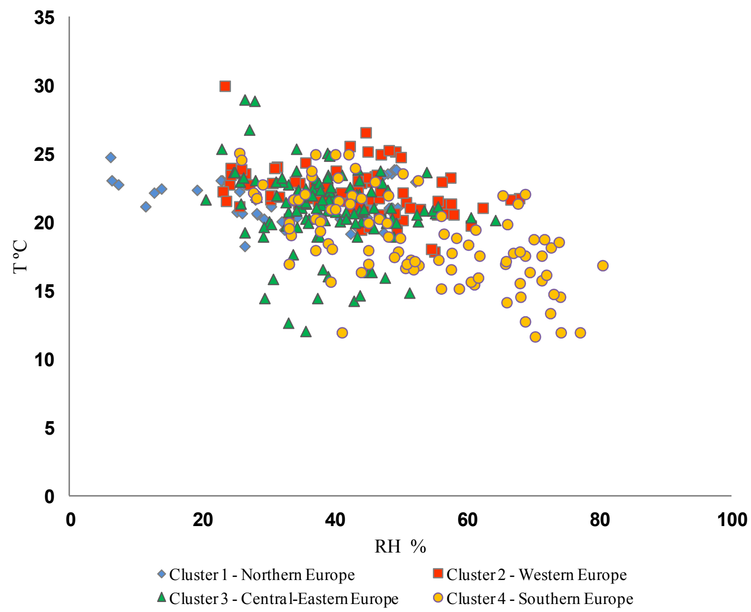


Figure 31. Distribution of temperature and relative humidity by SINPHONIE cluster

The statistical values for temperature and relative humidity are presented in Table 17, grouped by SINPHONIE cluster.

Table 17. Distribution of temperature and relative humidity by cluster

	Temperature (ºC)			Relative humidity (%)		
	Mean	Min	Max	Mean	Min	Max
Cluster 1 – Northern Europe	21.7	18.3	24.8	33.4	6.0	56.1
Cluster 2 –Western Europe	22.3	17.9	30	42.7	23.0	67.8
Cluster 3 – Central-Eastern Europe	21.0	12.1	29.0	38.7	20.4	64.2
Cluster 4 -– Southern Europe	18.9	11.7	25.1	51.4	25.5	80.4
All data	20.8	11.7	30.0	42.6	6.0	80.4

The differences between SINPHONIE clusters in terms of relative humidity and temperature distributions are also presented in Figure 32. The highest relative humidity was measured in Cluster 4 (Southern Europe) and the lowest in Cluster 1 (Northern Europe). Concerning temperatures, the minimum value was measured in Cluster 4 (Southern Europe) and the maximum in Cluster 2 (Western Europe).

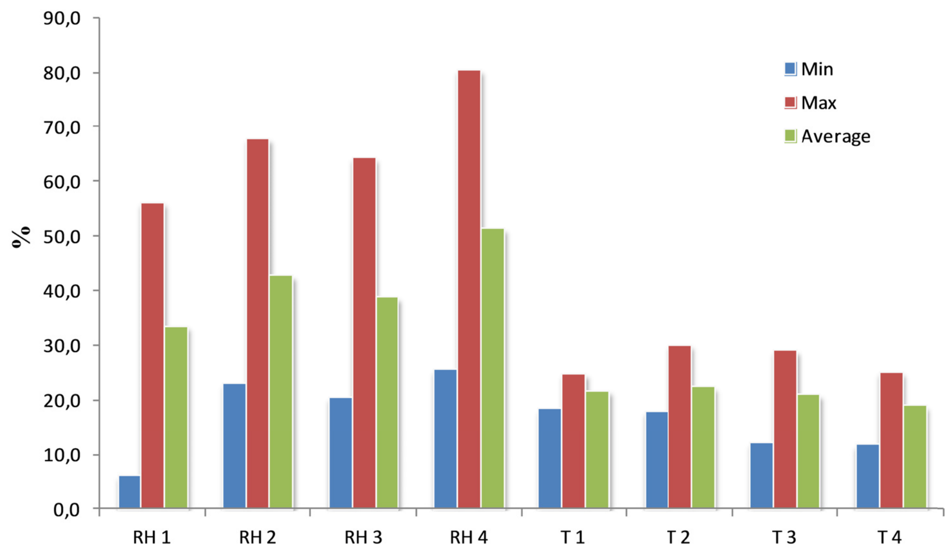


Figure 32. Distribution of relative humidity and temperature by SINPHONIE cluster

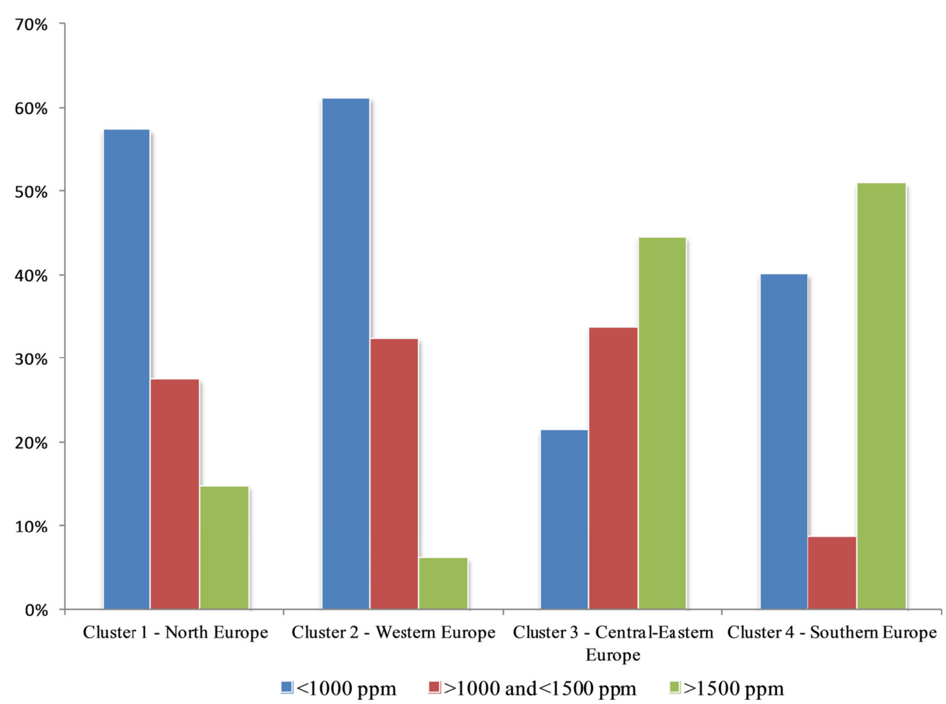


Figure 33. Distribution of CO_2 concentrations by SINPHONIE cluster

The distribution of CO_2 concentration levels by SINPHONIE cluster is presented in Figure 33, which shows that Cluster 1 (Northern Europe) and Cluster 2 (Western Europe) present the highest percentages of classrooms with low levels of CO_2 (<1,000 ppm), whereas Cluster 3 (Central-Eastern Europe) and Cluster 4 (Southern Europe) present the highest percentages of classrooms with CO_2 levels higher than 1,500 ppm.

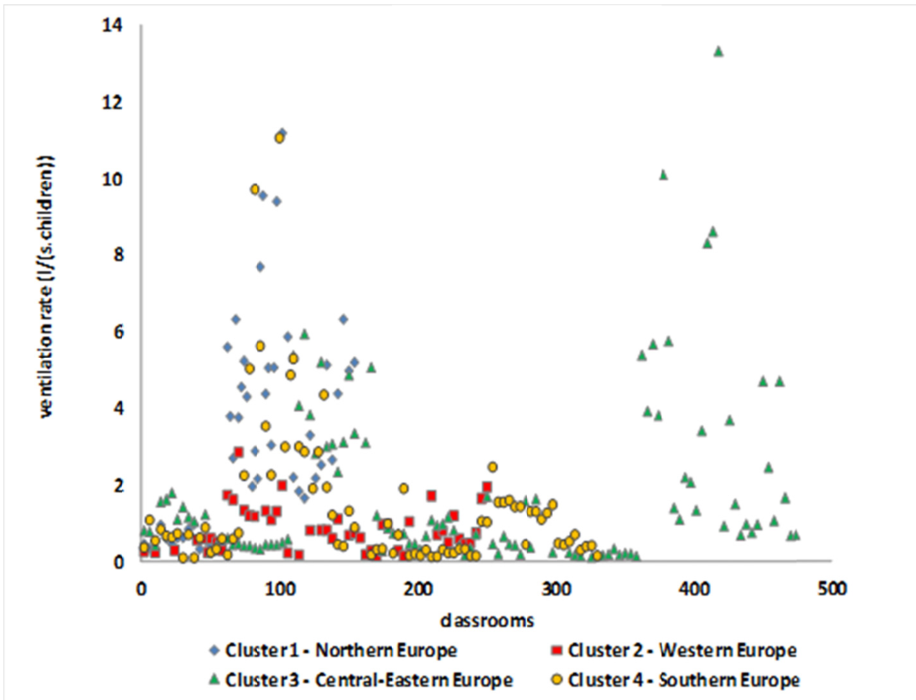


Figure 34. Distribution of ventilation rates by SINPHONIE cluster

The majority of the values for ventilation (86%) are lower than the desired value of 4 l/s.child. The distribution of ventilation rates by SINPHONIE cluster is presented in Figure 34.

The statistical values for ventilation rates are presented by SINPHONIE cluster in Table 18.

Table 18. Distribution of ventilation rates by cluster

	Ventilation rate (l/s.child)		
	Mean	Min	Max
Cluster 1 – Northern Europe	3.39	0.35	11.20
Cluster 2 – Western Europe	0.87	0.17	2.87
Cluster 3 – Central-Eastern Europe	1.82	0.14	13.33
Cluster 4 – Southern Europe	1.42	0.12	11.08
All data	1.80	0.12	13.33

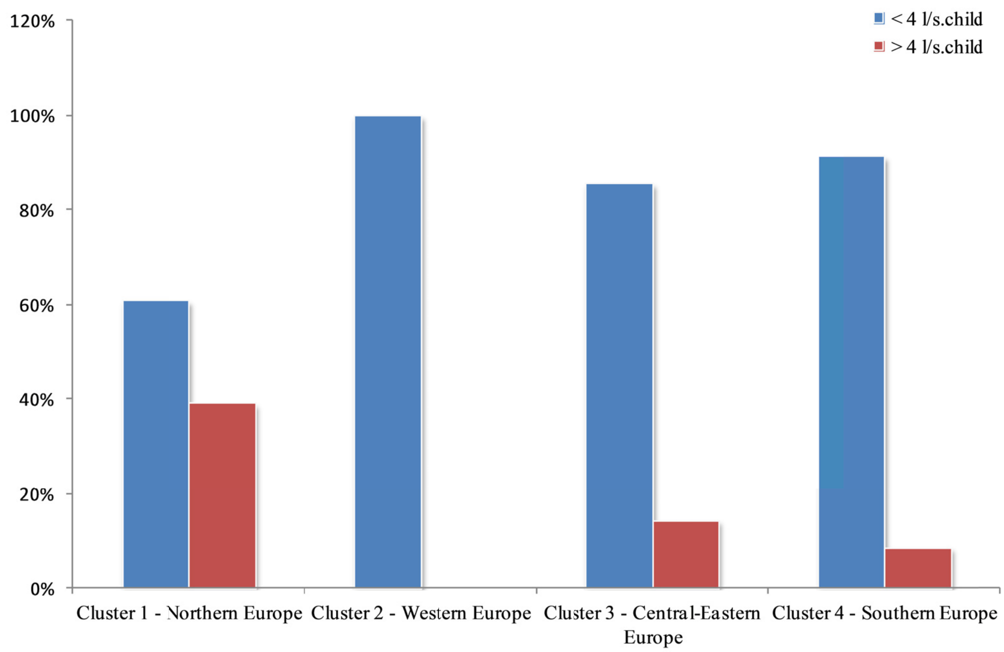


Figure 35. Percentage of classrooms with a ventilation rate higher or lower than 4 l/s. Child

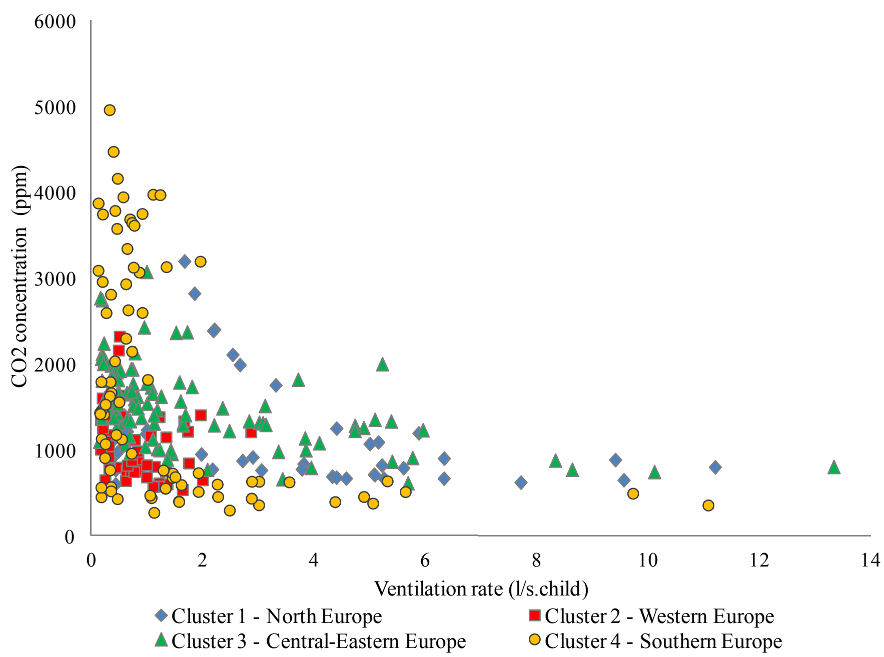


Figure 36. Distribution of ventilation rates and CO_2 concentrations by SINPHONIE cluster

The lowest value is found in Cluster 4 (Southern Europe), although all the values measured in Cluster 2 (Western Europe) are lower than the desired value. Cluster 1 (Northern Europe) presents a higher percentage of classrooms with a ventilation rate higher than the recommended level. In Cluster 2 (Western Europe) no room was found with a ventilation rate higher than 4 l/s. child, whereas in Cluster 3 (Central-Eastern Europe) and Cluster 4 (Southern Europe), less than 20% of classrooms had a ventilation rate higher than 4 l/s. child, and in Cluster 1 (Northern Europe) approximately 40% of the classrooms had a ventilation rate higher than 4 l/s. child (Figure 35).

The values for ventilation are associated with CO_2 concentrations in Figure 36, which shows that higher ventilation rates lead to a lower CO_2 concentration, as expected.

4.3.3 Microbiological contaminants

Observed levels

The monitoring of the SINPHONIE classrooms and kindergartens revealed an enormous range in the levels of individual microbes (Tables 19 to 21). In addition, extremely elevated maximal values were observed for all bio-contaminants. The bio-contaminant with the highest median levels in the SINPHONIE schools and kindergartens was PenAsp, followed by Myco cells and Strep cells. This is not surprising, since these agents represent larger taxonomic groups of fungi and bacteria compared to, for example, *Aspergillus versicolor, Trichoderma viride, Cladosporium herbarum or Alternaria alternata,* which are individual fungal species. Endotoxins cannot be compared to the other microbial measurements due to differences in the type of agent, sample material and analysis approach. Median levels of microbes varied between countries by approximately two orders of magnitude for fungi and by approximately one order of magnitude for bacteria. Large differences were also visible in the case of some of the microbial agents between schools/classrooms within a country, and extreme values were observed in single samples. There was no clear trend towards countries or SINPHONIE clusters of countries being prone to consistently higher or lower microbial levels. Differences in median rank, based on the median levels in the countries, were observed between the microbial agents. Tables 19, 20 and 21 summarise the distribution of bio-contaminants among schoolchildren, kindergarten children and teachers, this differentiation being relevant for subsequent health analyses. The tables show the distribution of microbial indoor contaminants in SINPHONIE classrooms by country. (Note: the boxes represent the 25th percentile, the median and the 75th percentile; the small quadrangles indicate mean values; whiskers range to minimum and maximum values measured in classrooms per country).

Comparison with guideline values and results in the literature

No comparisons can be made at the level of microbial contaminants observed in SINPHONIE classrooms in relation to EU limit values and WHO guidelines, as neither exists for specific microbes. Even at national level, only in a very few European countries guidance is provided with respect to indoor microbial levels (and this refers exclusively to levels of viable fungi and/or bacteria from short-term active air samples that are mostly valid for the home environment rather than schools). With respect to the measurement of indoor microbial agents, SINPHONIE has done pioneering work and has laid the foundations for the development of respective guidance at European level. Innovative methods for the sampling and analyses of microbes, which are expected to dominate future microbial exposure assessments, were implemented in SINPHONIE. It should be noted that the results of the endotoxin measurements obtained in the SINPHONIE project compare well to those reported in a recent school study under the Health Effects of Indoor Pollutants project (HITEA) [44], using the same sampling and analysis approach. This indicates the need to use standardised sampling approaches and analysis protocols for bio-contaminants in order to produce data that are well comparable between studies, using innovative and cultivation-independent approaches.

Table 19. Distribution of microbiological agents and allergens in SINPHONIE primary schools (N=292)

Bio-contaminants	Mean	Median	Min	Max	CV%
Endotoxin[1]	10080.1	7114.0	496.0	59000.0	95.6
PenAsp cells[2]	726149.3	63154.5	1143.0	24739120.0	382.0
Avers cells[2]	378.0	0.0	0.0	55671.0	932.8
Tviri cells[2]	301.2	10.0	0.0	72308.0	1440.6
Cherb cells[2]	923.5	268.5	0.0	69322.0	466.2
Aaltr cells[2]	39.2	8.0	0.0	4406.0	684.0
Strep cells[2]	42252.7	16914.0	0.0	1268072.0	238.0
Myco cells[2]	147504.4	51191.0	0.0	6401677.0	299.9
Cat allergen[3]	86.5	0.0	0.0	1762.0	244.1
Dog allergen[3]	103.5	0.0	0.0	1745.0	215.2
Horse allergen[3]	80.3	0.0	0.0	2630.0	498.5
Der p1 allergen[3]	4.9	0.0	0.0	337.0	751.5
Der f1 allergen[3]	2.8	0.0	0.0	167.0	713.7

CV: coefficient of variation; [1] units/m^2; [2] units/mg dust (qPCR); [3] units/g dust

Note: the determination of house dust mite and horses allergens took place in a restricted number of classrooms in primary schools (N=99) and results were not considered as satisfactory for kindergarten children.

Table 20. Distribution of microbiological agents and allergens in SINPHONIE kindergartens (N=25)

Bio-contaminants	Mean	Median	Min	Max	CV%
Endotoxin[1]	7358.0	7956.0	2565.0	12768.0	42.9
PenAsp cells[2]	88074.0	34830.0	2621.0	622039.0	168.9
Avers cells[2]	21.2	0.0	0.0	320.0	312.0
Tviri cells[2]	29.4	2.0	0.0	296.0	266.4
Cherb cells[2]	171.0	37.0	5.0	807.0	138.6
Aaltr cells[2]	6.7	0.0	0.0	40.0	163.3
Strep cells[2]	23856.3	6859.0	1556.0	227616.0	203.6
Myco cells[2]	81163.6	32155.0	4735.0	580782.0	172.3
Cat allergen[3]	90.6	0.0	0.0	1285.0	288.8
Dog allergen[3]	70.0	0.0	0.0	468.0	185.7

CV: coefficient of variation; [1] units/m^2; [2] units/mg dust (qPCR); [3] ng/g dust

Note: the determination of house dust mite and horses allergens took place in a restricted number of classrooms and results were not considered as satisfactory for kindergarten children.

Table 21. Distribution of microbiological agents and allergens in SINPHONIE primary schools where teachers participated (N=106)

Bio-contaminants	Mean	Median	Min	Max	CV%
Endotoxin[1]	10160.9	7660.0	576.0	39565.0	79.7
PenAsp cells[2]	672290.7	75055.0	4173.0	14830440.0	338.1
Avers cells[2]	345.0	2.5	0.0	18567.0	588.0
Tviri cells[2]	276.6	12.0	0.0	24213.0	866.2
Cherb cells[2]	871.0	317.0	4.0	27209.0	317.7
Aaltr cells[2]	36.7	8.0	0.0	1480.0	406.6
Strep cells[2]	40250.9	19486.5	1927.0	466939.0	164.8
Myco cells[2]	148561.6	70108.5	2088.0	2417766.0	194.8
Cat allergen[3]	85.3	35.5	0.0	683.0	164.3
Dog allergen[3]	100.3	9.0	0.0	790.0	161.6
Horse allergen[3]	77.1	0.0	0.0	2630.0	508.9
Der p1 allergen[3]	4.8	0.0	0.0	337.0	762.9
Der f1 allergen[3]	2.7	0.0	0.0	167.0	724.5

CV: coefficient of variation; [1] units/m^2; [2] units/mg dust (qPCR); [3] ng/g dust
Note: concentrations of bio-contaminants were assessed using school means

4.3.4 Allergens

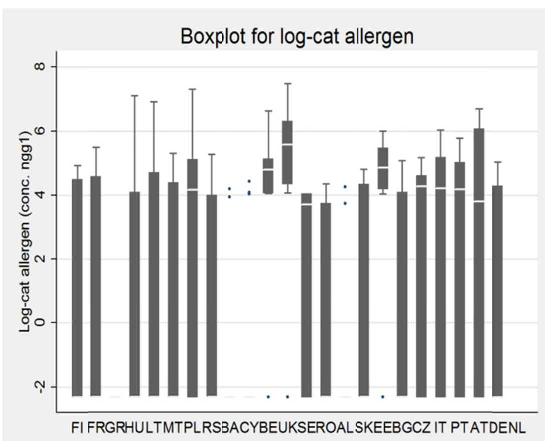
Observed levels

Allergens, the bio-contaminants known to be responsible for allergic health outcomes, had not been extensively assessed in the school environment prior to the SINPHONIE project. Targeted allergens in SINPHONIE were the house dust mite (Der f1, Der p1), and cat, dog and horse allergens. There were large variations in allergen levels between classrooms, schools and centres in SINPHONIE. The median level of all types of allergens in the classrooms was zero, showing that the majority of the classrooms did not contain allergens above the detection limits. However, the maximum levels were considerably higher in schools compared to kindergartens. The mean levels of allergens in schools where health data were retrieved for teachers were similar to the total level of allergens for classrooms with participating children.

There was a considerable variation in mean allergen levels between the participating countries. The country mean values varied by two orders of magnitude for cat allergen and more than four orders of magnitude for dog allergen. Horse allergen was detected in a few countries. Since furry pets are not common in schools, the source of the contamination is attributed to allergens transported from the homes of pet keepers to the school environment on their clothes or in their hair [81]. The number of pet keepers in the class is one major determinant of allergen levels in the dust [82, 3]. This is probably one of the main reasons for the large variation observed in allergen levels between the countries in the SINPHONIE study. In addition, cleaning frequency may be important. The daily cleaning of floors and surfaces above floor level (chairs, desks, curtains and other textiles) could reduce the level of dust and the level of exposure in classrooms or kindergartens. The use of special clothes at school, which are not worn at home, has been shown to reduce allergen levels in the school dust [62].

Comparison with guideline values and results in the literature

It is difficult to set standards or guidelines for allergens, since a dose-response curve for allergens may be difficult (even impossible) to obtain compared to non-allergenic chemical compounds or particles. In fact, it is not at all clear that there is any dose-response association for allergens. A highly sensitised subject may have severe reactions even at very low levels of allergens, while a mildly sensitised subject can tolerate far higher levels and a non-sensitised subject does not have any adverse health effects at all when exposed to allergens. However, despite these potential problems, some guidelines for allergens in dust can be compiled. It has been suggested that levels below 1,000 ng/gram of dust can be considered as safe levels for avoiding allergic sensitisation for cat (Feld 1) and dog allergens (Can f1), with a corresponding non-effect level below 2,000 ng/g of dust for Der f (one house dust mite allergen). Data have shown that with levels above 8,000 ng/g dust for cat allergen, 10,000 ng/g of dust for dog allergen and 10,000 ng/g of dust for Der p1, there is an increased risk of asthma exacerbation [81]. According to these guidelines, none of the SINPHONIE classrooms exceeded the suggested upper limit value at which the exacerbation of asthma could occur (Tables 19, 20 and 21). Only a few classrooms had levels of cat and dog allergens above the non-effect level of 1,000 ng/g of dust for these allergens. The levels of house dust mite allergen were well below the safe level for all classrooms investigated.



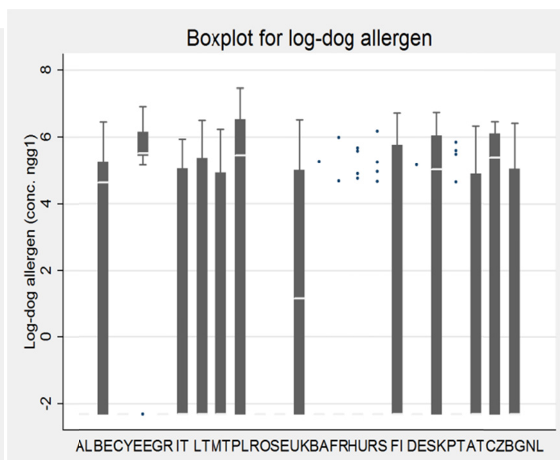


Figure 37. Distribution of cat allergen by country **Figure 38.** Distribution of dog allergen by country

Note: The boxplots are sorted in ascending order by their country-specific mean values. The lozenge shapes in the boxplots denote the means, and the horizontal bars denote the medians, of the distribution.

4.4 Building characteristics and air pollution sources

The building characteristics reported in this section are based on the evaluation of the SINPHONIE questionnaires.

4.4.1 Classroom facing the street

The mean concentration of T3CE, a Group 2A carcinogen (i.e. probably carcinogenic to humans in accordance with the provisions of Regulation EC No 1272/2008) was significantly higher in classrooms facing the street than in classrooms oriented towards the schoolyard (8.8 μg/m^3 and 2.1 μg/m^3, respectively). Taking the WHO guideline value [125] of 23 μg/m^3 as a cut-off point, significantly more classrooms had a T3CE concentration above this value among those facing the street than among those oriented towards the schoolyard (9.0% and 2.3% respectively) (Figure 39). Logistic regression analysis revealed a 4.27 times increased risk for a T3CE concentration above the WHO guideline value among the street-oriented classrooms, and this association remained statistically significant even after adjustment for country.

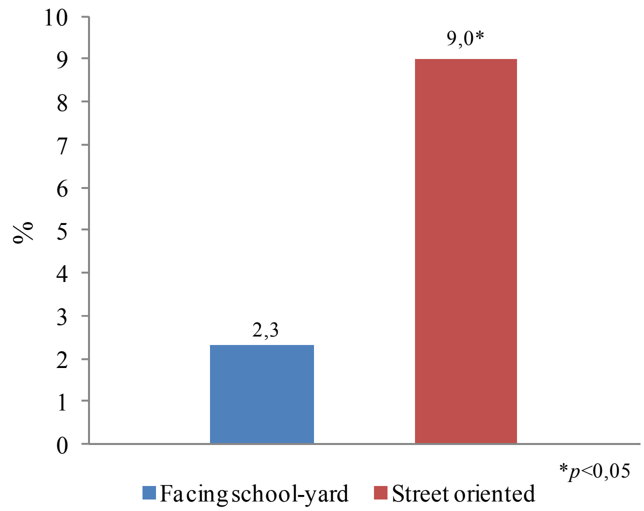


Figure 39. Percentage of SINPHONIE classrooms with an indoor T3CE concentration above 23 μg/m^3, according to orientation (facing the street or the schoolyard)

4.4.2 Floor level of the classroom

As expected, radon concentrations were significantly higher in classrooms on the lower floors of the building than in classrooms on higher floors.

4.4.3 Occupation density

The mean CO_2 concentration was significantly higher in classrooms with a higher occupation density (less than 1.5 m^2/person) (Figure 40). The results of linear regression analysis showed that the negative association between floor space per child and the logarithm of CO_2 concentrations remained statistically significant ($p<0.001$) even after adjustment for country. Radon concentrations were also higher in classrooms with a higher occupation density.

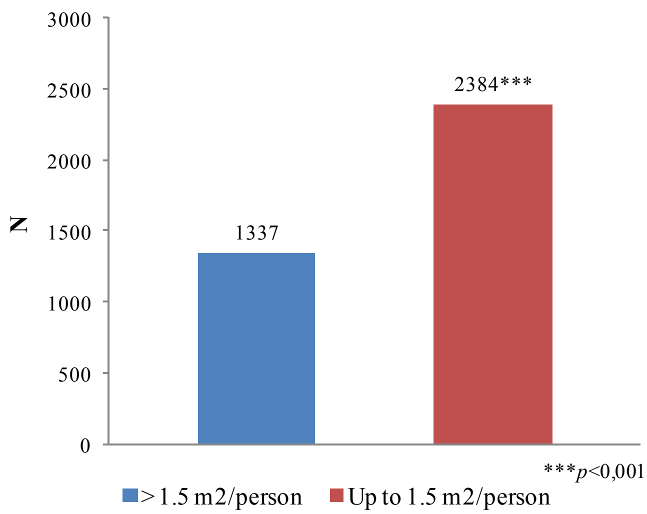


Figure 40. Mean CO_2 concentrations according to occupation density in SINPHONIE classrooms

4.4.4 Wall paints used in the classroom

Measured concentrations of T3CE were higher in classrooms painted with water-resistant paint (especially in those painted within one year of the SINPHONIE campaign) than in other classrooms, although after adjustments these associations were no longer significant. However, measured $PM_{2.5}$ concentrations were significantly higher in classrooms that were freshly (<1 year) painted with water-resistant paints (mean concentrations: 81.9 µg/m^3 and 41.4 µg/m^3 respectively), and this association remained statistically significant even after adjustment for country.

Only eight classrooms had walls freshly (<1 year) painted with whitewash. Benzene concentrations measured in these classrooms were significantly higher (mean concentration 12 µg/m^3) than in other classrooms (mean concentration 4.0 µg/m^3). This association remained statistically significant even after adjustment for country. Indoor NO_2 levels were also statistically significantly higher (mean concentrations 33.8 µg/m^3 and 13.6 µg/m^3 respectively) in these classrooms, and they also remained so after adjustment for country.

4.4.5 Mechanical ventilation

About 11% of the SINPHONIE classrooms featured mechanical ventilation. In these classrooms the concentration of CO_2 was significantly lower than in classrooms without mechanical ventilation (mean values 1,087 ppm and 1,510 ppm, respectively). Linear regression analysis showed that the significant association between the logarithm of CO_2 and mechanical ventilation remained significant even after adjustment for country.

On the other hand, measured ozone concentrations were significantly higher in classrooms with mechanical ventilation than in those without mechanical ventilation (mean values 14.1µg/m^3 and 5.9 µg/m^3, respectively). The association between the logarithm of ozone concentrations and mechanical ventilation also remained statistically significant, even after adjustment for country.

4.4.6 Vacuum cleaner used for cleaning

In 23% of the SINPHONIE classrooms, vacuum cleaners were used for cleaning. In these classrooms the measured concentrations of formaldehyde, pinene and NO_2 were significantly higher than in classrooms not cleaned with a vacuum cleaner. All these differences remained statistically significant after adjustment for country (Figure 41).

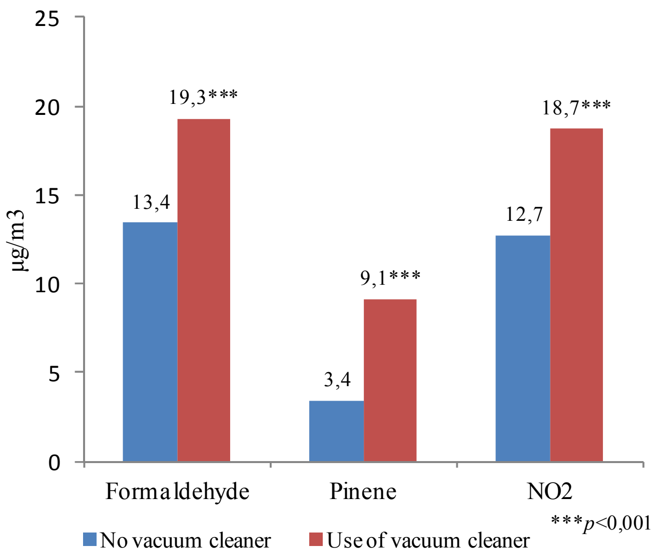


Figure 41. Mean concentrations of formaldehyde, pinene and NO_2 in SINPHONIE classrooms cleaned with or without a vacuum cleaner

4.4.7 Mop with bleach used for cleaning

Mops with bleach were used in 18.5% of the SINPHONIE classrooms. Indoor concentrations of both formaldehyde and pinene were significantly higher in these classrooms than in those not cleaned with bleach. In the case of formaldehyde, this difference remained statistically significant after adjustment for country, while the linear regression association between the logarithm of pinene concentration and the use of a mop with bleach was of borderline significance (p=0.062) after adjustment for country.

4.4.8 Classroom with mouldy odour

A mouldy odour was found in 8.2% of the SINPHONIE classrooms. The mean concentration of CO_2 measured in these classrooms was significantly higher (1,844 ppm) than in those without a mouldy odour (1,436 ppm). Linear regression analysis revealed a significant association between the logarithm of CO_2 and mouldy odour, even after adjustment for country. Significantly more classrooms (66.7%) had CO_2 concentrations above 1,500 ppm among those with a mouldy odour than among those without a mouldy odour (34.2%). This difference also remained statistically significant after adjustment for country (Figure 42).

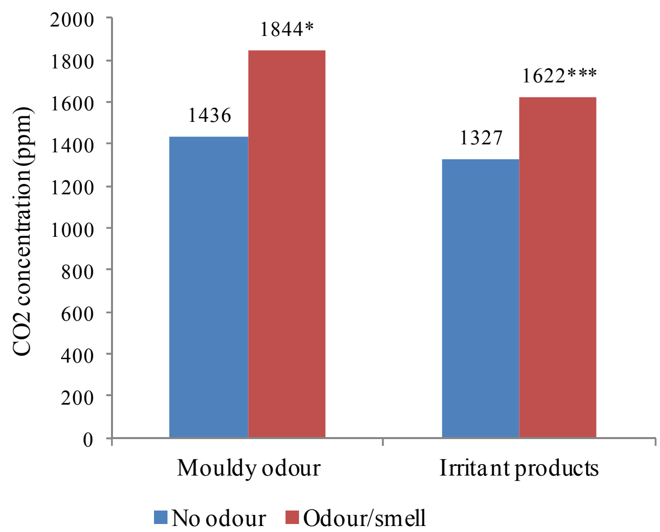


Figure 42. Mean CO_2 concentrations in SINPHONIE classrooms with or without a mouldy odour or using products with an irritant smell (*** p<0,001; * p<0,05)

4.4.9 Use of products with an irritant smell

Significantly higher concentrations of CO_2 were measured in SINPHONIE classrooms in which children often used products with an irritant smell. Linear regression analysis showed a significant association between the logarithm of CO_2 and the use of products with an irritant smell, even after adjustment for country. In this case again, significantly more classrooms with a mouldy odour (44.6%) had CO_2 concentrations above 1,500 ppm than those without a mouldy odour (28.9%). This difference also remained statistically significant after adjustment for country.

Concentrations of $PM_{2.5}$ were also significantly higher in SINPHONIE classrooms where children used products with an irritant smell than in others (49.7 µg/m^3 and 40.3 µg/m^3, respectively). Linear regression analysis again showed a significant association between the logarithm of $PM_{2.5}$ and irritant smell, even after adjustment for country.

4.4.10 Visible signs of moisture in the classroom

As expected, significantly increased levels of relative humidity and decreased temperatures were observed in SINPHONIE classrooms with visible signs of moisture. These associations remained statistically significant even after adjustment for country.

4.4.11 Dusty classrooms

In dusty SINPHONIE classrooms, significantly increased levels of NO_2 were measured. The results of linear regression analysis showed that the association between the logarithm of NO_2 and dusty classrooms lost its statistical significance after adjustment for country.

4.5 Outdoor air pollution

Levels of outdoor air pollution assessed in the vicinity of SINPHONIE schools were elevated in the case of the traffic-related air pollutants $PM_{2.5}$, NO_2 and ozone. However, the levels varied according to geographical region (Tables 22, 23, 24 and 25) During the heating season, average $PM_{2.5}$ levels were above the WHO guideline [WHO 2005 guideline values [120] for $PM_{2.5}$ are 25 µg/m^3 (24-hour mean) and 10 µg/m^3 (annual mean)], value in all clusters, the maximum being observed in Cluster 3 (Central-Eastern Europe) (42 µg/m^3). During the non-heating season, schools in Cluster 1 (Northern Europe) were less exposed to outdoor air pollutants than schools in the other clusters.

Table 22. Distribution of chemical parameters in the countries of Cluster 1 (Northern Europe)

Parameter	N	Mean	SD	p50	Min	Max	CV
Formaldehyde[1]	13	1.44	0.53	1.60	0.27	2.23	0.37
Benzene[1]	13	1.52	1.25	1.29	0.18	4.68	0.82
Limonene[1]	13	0.00	0.00	0.00	0.00	0.00	.
NO_2[1]	13	17.73	26.47	7.00	2.33	98.37	1.49
Ozone[1]	13	33.84	15.64	29.00	9.42	64.00	0.46
Naphthalene[1]	13	**0.00**	0.00	0.00	0.00	0.00	.
$PM_{2.5}$[1]	12	29.46	15.30	29.30	3.20	50.48	0.52
CO_2[2]	10	410.23	73.18	398.70	323.00	573.30	0.18
T3CE[1]	13	0.00	0.00	0.00	0.00	0.00	.
T4CE[1]	13	0.00	0.00	0.00	0.00	0.00	.
CO [2]	13	0.37	0.61	0.00	0.00	1.48	1.63
Radon[3]	8	48.51	29.44	44.60	14.80	114.50	0.61

SD: standard deviation; p50: 50th percentile; Min: minimum; Max: maximum; CV: coefficient of variation; T3CE: trichloroethylene; T4CE: tetrachloroethylene; [1] µg/m^3; [2] ppm (parts per million); [3] Bq/m^3

Table 23. Distribution of chemical parameters in the countries of Cluster 2 (Western Europe)

Parameter	N	Mean	SD	p50	Min	Max	CV
Formaldehyde[1]	24	2.35	2.75	1.62	0.34	14.57	1.17
Benzene[1]	24	1.07	0.88	0.75	0.00	3.40	0.82
Limonene[1]	24	0.34	1.22	0.00	0.00	6.02	3.64
NO_2[1]	24	29.51	9.62	29.14	13.18	49.38	0.33
Ozone[1]	23	13.78	12.52	9.00	0.00	39.00	0.91
Naphthalene[1]	15	0.17	0.54	0.00	0.00	2.12	3.28
$PM_{2.5}$[1]	15	23.16	17.28	23.97	3.30	69.60	0.75
CO_2[2]	15	410.33	42.62	424.00	317.00	472.00	0.10
T3CE[1]	24	0.02	0.08	0.00	0.00	0.37	4.52
T4CE[1]	24	0.07	0.16	0.00	0.00	0.65	2.11
CO [2]	12	0.07	0.10	0.03	0.00	0.30	1.36
Radon[3]	15	62.26	54.18	57.00	0.00	173.60	0.87

SD: standard deviation; p50: 50th percentile; Min: minimum; Max: maximum; CV: coefficient of variation; T3CE: trichloroethylene; T4CE: tetrachloroethylene

Table 24. Distribution of chemical parameters in the countries of Cluster 3 (Central-Eastern Europe)

Parameter	N	Mean	SD	p50	Min	Max	CV
Formaldehyde[1]	41	5.03	6.42	3.30	0.62	40.18	1.28
Benzene[1]	40	4.04	3.82	3.56	0.00	17.70	0.94
Limonene[1]	40	0.92	1.91	0.00	0.00	7.59	2.07
NO_2[1]	41	19.94	13.54	14.34	6.00	58.49	0.68
Ozone[1]	41	82.79	141.39	21.85	0.00	745.64	1.71
Naphthalene[1]	36	1.64	3.16	0.08	0.00	10.54	1.92
$PM_{2.5}$[1]	41	57.80	39.93	42.90	13.82	181.81	0.69
CO_2[2]	40	414.31	121.88	413.20	171.39	761.56	0.29
T3CE[1]	40	0.20	0.81	0.00	0.00	4.30	4.02
T4CE[1]	40	0.80	2.27	0.00	0.00	10.01	2.83
CO [2]	41	0.44	0.60	0.30	0.00	2.79	1.35
Radon[3]	20	28.15	18.43	23.50	9.00	90.00	0.65

SD: standard deviation; p50: 50th percentile; Min: minimum; Max: maximum; CV: coefficient of variation; T3CE: trichloroethylene; T4CE: tetrachloroethylene; [1] µg/m³; [2] ppm (parts per million); [3] Bq/m³

Table 25. Distribution of chemical parameters in the countries of Cluster 4 (Southern Europe)

Parameter	N	Mean	SD	p50	Min	Max	CV
Formaldehyde[1]	29	2.64	1.30	2.49	0.00	4.90	0.49
Benzene[1]	29	3.09	1.92	2.42	0.90	9.30	0.62
Limonene[1]	23	4.43	7.65	0.71	0.00	31.50	1.73
NO_2[1]	29	24.79	23.80	16.57	3.48	101.40	0.96
Ozone[1]	28	100.41	90.05	63.77	0.00	321.47	0.90
Naphthalene[1]	23	0.43	0.59	0.00	0.00	1.96	1.37
$PM_{2.5}$[1]	27	31.67	20.98	24.71	4.52	104.69	0.66
CO_2[2]	29	520.47	191.28	455.00	334.00	1102.00	0.37
T3CE[1]	23	0.29	1.37	0.00	0.00	6.57	4.80
T4CE[1]	23	0.79	1.41	0.00	0.00	4.40	1.80
CO [2]	28	1.44	3.48	0.16	0.00	12.98	2.41
Radon[3]	9	47.11	56.69	23.00	11.00	182.00	1.20

SD: standard deviation; p50: 50th percentile; Min: minimum; Max: maximum; CV: coefficient of variation; T3CE: trichloroethylene; T4CE: tetrachloroethylene; [1] µg/m³; [2] ppm (parts per million); [3] Bq/m³

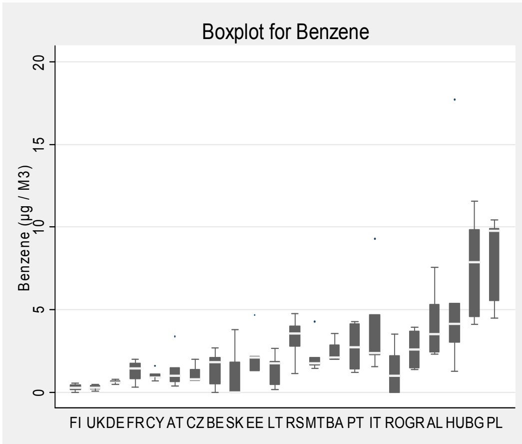


Figure 43. Distribution of benzene by country

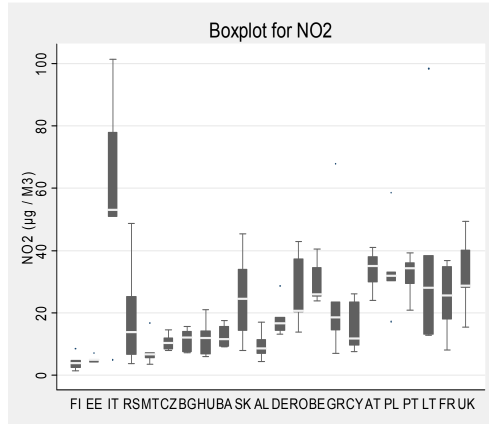


Figure 44. Distribution of NO_2 by country

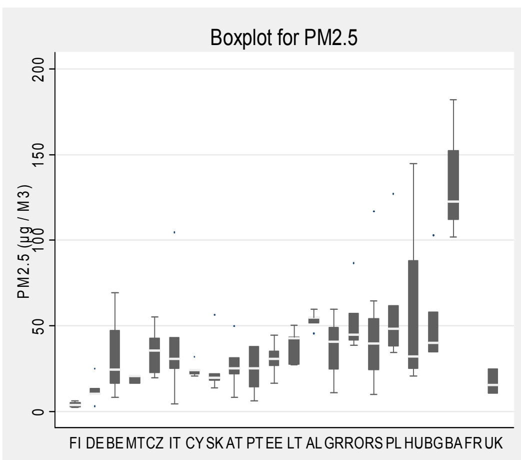


Figure 45. Distribution of $PM_{2.5}$ by country

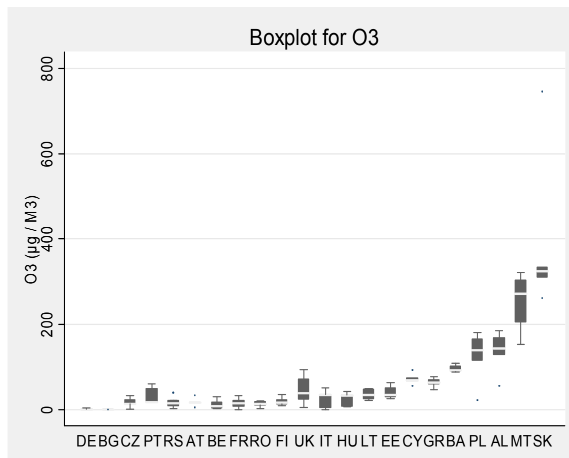


Figure 46. Distribution of ozone by country

4.6 The impact of outdoor air pollution and climate change on school air quality

The impact of outdoor air pollution on the air quality in classrooms was estimated by calculating, for each air pollutant, the ratio of the mean indoor concentration to the outdoor concentration (I/O ratio). If this ratio is higher than 1 for an air pollutant, it indicates that the concentration of this air pollutant is more elevated indoors than outdoors and that therefore the major contributors of this air pollutant are indoor sources. Likewise, a ratio of less than 1 indicates that the major source of indoor air pollution is outdoor air pollution. As expected, NO_2 and ozone levels were higher outdoors than indoors. However, $PM_{2.5}$ found in the SINPHONIE classrooms resulted mostly from indoor rather than outdoor sources, as shown by the I/O ratio of 1.4. All the other air pollutants were emitted mostly from indoor sources (Table 26).

Table 26. Indoor/outdoor ratio for chemical, physical and comfort parameters ($r_{I/O}$)

Parameter	$N_{schools}$§	Indoor mean	Outdoor mean	I/O ratio mean	$r_{I/O}$	*p*-value
Formaldehyde[1]	105	15.2	3.0	7.4	0.35	0.000***
Benzene[1]	100	4.0	2.7	1.5	0.89	0.000***
Naphthalene[1]	33	2.2	0.9	3.7	0.68	0.000***
Limonene[1]	40	36.2	1.5	44.5	0.13	0.182
NO_2[1]	106	13.9	22.4	0.8	0.75	0.000***
$PM_{2.5}$[1]	96	45.3	39.9	1.4	0.74	0.000***
Ozone[1]	90	8.1	71.0	0.1	0.82	0.000***
CO [2]	56	0.9	0.5	6.0	0.37	0.000***
CO_2[2]	97	1,467.7	445.7	3.5	0.09	0.365
T3CE[1]	13	3.4	0.2	20.4	0.51	0.000***
T4CE[1]	26	1.2	0.5	1.4	0.75	0.000***

T3CE: trichloroethylene; T4CE: tetrachloroethylene; Mean I/O ratio: mean ratio of indoor air pollutant concentration to outdoor air pollutant concentration; $r_{I/O}$: Spearman's correlation coefficient (*p*-value) between indoor and outdoor pollutant concentration; Indoor mean concentration: computed over classrooms and seasons in a school for a pollutant; Outdoor mean concentration: computed over seasons in a school for a pollutant.

[1] $\mu g/m^3$; [2] ppm (parts per million); ***$p < 0.001$.

§ Note 1: the $N_{schools}$ reported here for the statistic "I/O ratio mean" could be different from (i.e. less than) $N_{schools}$ for the indoor and outdoor pollutant concentration means carried out individually (not shown) due to division by a zero denominator in computing the I/O_{ratio} means (i.e. the outdoor pollutant concentration being equal to zero in such cases, especially for volatile organic compounds). Note 2: the I/O mean is computed for a ratio, which is not equal to dividing the mean indoor pollutant concentration by the mean outdoor pollutant concentration.

An assessment of the degree to which traffic-induced air pollution affects IAQ in classrooms is an important element in designing appropriate strategies and management options for better IAQ in school environments. A methodology was developed within the framework of SINPHONIE on the basis of a statistical analysis of measurements of traffic-related pollutants both outdoors and indoors.

The experimental data were taken from two countries (Greece and Portugal) in Cluster 4 (Southern Europe), which are characterised by mild winters and hot summers and which often experience intense heat waves and dry spells. Schools in this group rely mostly on natural ventilation during the cold and warm seasons, while overall the insulation of school buildings is moderate. The results obtained within SINPHONIE show that the airflow rate varies during teaching hours and increases significantly because of doors being opened and children entering and exiting the classrooms, while the end of the school day is marked by lower exchange ventilation rates. It should be noted that the ventilation rates differ in different classrooms, and that in many cases high ventilation rates are measured after school hours, probably due to cleaning. The fact that windows are kept closed during teaching hours is indicated by lower exchange rates, although not as low as expected, probably due to the air transfer between rooms, as air moves even under the doors, and also to the fact that the buildings have visible cracks, which, as the literature suggests, are a major factor in the mass exchange of outdoor and indoor air and the entry of outdoor air indoors.

Climate change may alter atmospheric conditions, increasing the length of hot spells and the frequency of heat waves. In parallel, the heat island phenomenon may be increased due to climate change in specific urban zones. This potential change in atmospheric conditions may affect indoor conditions, airflow through the windows, and the concentration of pollutants in school buildings.

In this study, we characterised the temperature changes in Europe using the HadGEM1 climate model and assuming two SRES scenarios — moderate GHG emissions (A1B) and higher emissions (A2). The time period 1971 to 2000 was considered as the baseline period and the predictions referred to two time periods: 2021 to 2050; and 2071 to 2100. For the period 2021 to 2050, the predicted increase in temperature was similar in both scenarios. An increase in temperature of 1 or 2°C was predicted for most of Europe, although in Northern Europe a slightly higher increase of 2 or 3°C was predicted, and in some far northern areas an increase of more than 3°C was foreseen.

For the time period 2071 to 2100, the increase in temperature will continue with a similar spatial distribution. According to the A1B scenario, a temperature increase higher than 3 to 4°C can be predicted for most parts of Europe. The increase will surpass 4°C in Central Europe and the Iberian Peninsula. In the case of the A2 scenario, the temperature rise will be greater than 4°C in the majority of the European region. In Northern Europe, the spatial distribution of the temperature increase according to the A2 scenario is very similar to that of A1B, although a temperature 1°C higher is predicted.

Predictions of future changes in temperature in European cities were based on 12 cities involved in the SINPHONIE project. The highest temperature increase (over 100%) was predicted for cities in Northern Europe by the end of the 21st century. The lowest rate of increase was predicted for cities in the south and west, close to the sea and ocean. It was predicted that the warming will reach its highest rate in the period April to June in Northern Europe. In the western part of the continent, a higher rate of temperature increase was predicted after May, with a maximum increase in September, in cities in the Central European region. The monthly increase shows a similar tendency in southern cities as well, but the difference will reach the highest value in June and July. In southern cities along the coast, the temperature increase will be less than in the cities located to the north (for example Milan and Sofia), where the continental influence will affect the predicted temperature.

The health impacts of climate change are widely described in the literature. In Europe, some of these impacts may be positive, such as lower rates of cold-related mortality as a result of higher winter temperatures. However, on balance, without adaptive measures, health risks due to more frequent heat waves, especially in Southern, Central and Eastern Europe, flooding, and greater exposure to vector- and food-borne diseases are anticipated to increase.

Adaptive capacity needs to be improved throughout Europe. The impacts of recent heat waves show that even high-income countries are not well prepared to cope with extreme weather events. Diverse health impacts will be greater in economically less developed countries, and children are among the high-risk population. Economic development is an important component of adaptation, but on its own will not be sufficient. Several other factors should be taken into consideration, such as improvements to infrastructure and to education and health-care systems.

In terms of the impact of heat on children, it should be underlined that high outdoor, and consequently high indoor, temperatures (due to insufficient insulation, ventilation and shading, and inappropriate school building materials), may cause higher rates of headaches, fatigue and feeling very hot among schoolchildren, which in turn will result in lower physical and learning performance.

Climate change will also affect air quality. One of the subtasks of SINPHONIE WP3.4 was to evaluate changes to air quality under climate change scenarios (the HadAM3P [57] simulations for reference, and the IPCC SRES A2 climatic scenario were used to drive the MM5/CHIMERE modelling system).

The simulations within SINPHONIE made it possible to estimate the potential impacts of climate change on air quality (ozone and PM_{10}) in Berlin, Bratislava, Budapest, London, Milan, Prague, Porto, Sofia and Vienna. In general, the results indicate an increase in concentrations of these two pollutants under a future climate scenario in all the selected European cities. Schools located in these cities will therefore experience the impacts of climate change in the form of an increase in ozone and PM_{10} concentration levels and associated health impacts among children.

Within the framework of SINPHONIE WP3.4, the impacts of climate change were also assessed via the prediction of changes in temperature by season and month, and via the prediction of the consequences for the thermal comfort of children at school. The current situation was characterised by the findings of the school building questionnaires employed in SINPHONIE. The majority of the 122 examined school buildings were built from brick and concrete. In total, only 16% of the surveyed school buildings reported having insulated double walls, and 18% reported having insulated roofs. A higher percentage of schools in the countries of Cluster 1 (Northern Europe) had insulated walls and roofs than in the Central-Eastern and Southern clusters, which indicates that preventing cold is currently more important than coping with heat. The mean indoor air temperature in classrooms was more homogeneous in Northern and Western countries, and in the majority of cases was between 20 and 24ºC. Big differences were found in Central European and Mediterranean countries, where extreme mean temperature values were also recorded (12 and 28ºC respectively). These findings show that in countries where the annual mean temperature is low, greater attention is paid to ensuring thermal comfort in classrooms.

Summarising the findings of the school building questionnaire survey within SINPHONIE, it can be stated that the factors contributing to the heat resilience of schools are very different in the four European clusters. In Northern and Western European countries, insulation, heating and ventilation are better ensured than in Central-Eastern and Southern European countries, where buildings are in general not currently prepared to resist extreme thermal conditions (due to a lack of insulation and inefficient heating and ventilation). These conclusions are also supported by subjective perceptions of temperature among schoolchildren.

Because of the high number of schools involved in SINPHONIE, it was not possible to carry out a thorough (representative) analysis of predicted changes in heat exchange in all SINPHONIE schools. A case study was therefore undertaken using different archetypes of school buildings, where major similarities in architecture and thermal/energy performance could be found. For the purposes of this assessment, six cities in different European countries participating in the SINPHONIE project were selected based on the four SINPHONIE clusters and their climatic differences/similarities (Budapest, London, Paris, Stockholm, Porto and Athens). Climatic data from the selected cities were used to simulate and predict internal thermal conditions in schools by means of building thermal modelling. Prototypes of typical building typologies (Victorian, open air, contemporary, passive and energy efficient) were used to calculate energy consumption, using whole building energy model simulation via Energy Plus software. The basic concept of the modelling approach used is to create a virtual building in terms of its geometry, its construction materials and their characteristics, and its mechanical, electrical and lighting systems, and including any other system that may consume energy. Typical behaviour patterns among the occupants using the school building and their activity levels were also added to the models. To predict internal thermal conditions in future summers, weather data generated by UKCIP09 for the Design Summer Year (DSY) for medium GHG emissions scenarios (50^{th} percentile) were used.

It should be noted that naturally ventilated passive-design schools are the most thermally comfortable, followed by Victorian-design schools and energy-efficient schools. This can be explained by the better ventilation strategies and high internal thermal mass adopted in their design.

Open-air and contemporary-design schools have a higher risk of overheating in both present and future climatic conditions. This can be explained not only by the smaller internal thermal mass but also by the higher window to wall ratio in the building envelope. A higher window to wall ratio can lead to higher solar gains in internal spaces in the absence of solar shading devices.

Energy-efficient schools, which also have shaded windows in a highly insulated building envelope, fail to provide better thermal conditions inside, as they lack sufficient internal thermal mass that can be used for passive night cooling, which helps to improve day-time thermal conditions. Also, the insulation of the envelope in such schools not only prevents heat loss during winter but also retains the internal heat generated by pupils and electrical equipment during the summer.

The outcome of the case study also suggests that Victorian and passive-design schools will perform thermally better than other design typologies. Energy-efficient schools, even with insulated building envelopes, well-shaded windows and ample ventilation, fail to provide adequate thermal comfort because of their smaller internal thermal mass.

Recommended interventions and measures

The risk of overheating in schools can be reduced if greater exposed internal thermal mass is used with night cooling/purge ventilation, which helps to absorb the heat generated inside the classrooms even when the external temperature is higher than the thermal comfort limit.

Insulating the school building fabric from outside will also help to improve the thermal resistance of the school building envelope, preventing external heat gains and maintaining the existing thermal mass for use in night-time cooling.

School buildings with a high window to wall ratio can be upgraded by using insulated glazing panels and external shading devices to prevent solar and conductive heat gains through windows. Low-E coatings on glazing can significantly reduce direct and indirect infrared radiation, especially where it is difficult to provide external shading.

Reducing internal heat gains can also be a useful strategy for ensuring the thermal comfort of schoolchildren. This can be achieved by using energy-efficient lamps, lighting strategies and electrical equipment.

The outcome of the case study also suggests that there is significant scope for adaptive thermal comfort in classrooms, and that this will increase in the future. The need to adopt adaptive thermal comfort strategies in school buildings will increase, requiring pupils to wear lighter clothes, increasing the movement of indoor air passively by appropriate window design, or by using fans to help dissipate heat quickly during the summer season.

Low-energy comfort cooling can also be suggested in cities with warm climates such as Athens and Porto if passive-based measures alone make it difficult to achieve thermal comfort. Direct/indirect passive downdraught evaporative cooling, earth air tubes, and the use of phase change materials in air handling units to store free night cooling are examples of technologies for low-energy cooling.

4.7 Case studies on targeted indoor air quality issues

4.7.1 Ventilation effectiveness to enhance indoor air quality

Effectiveness of various natural ventilation strategies: the impact of seasonal variation

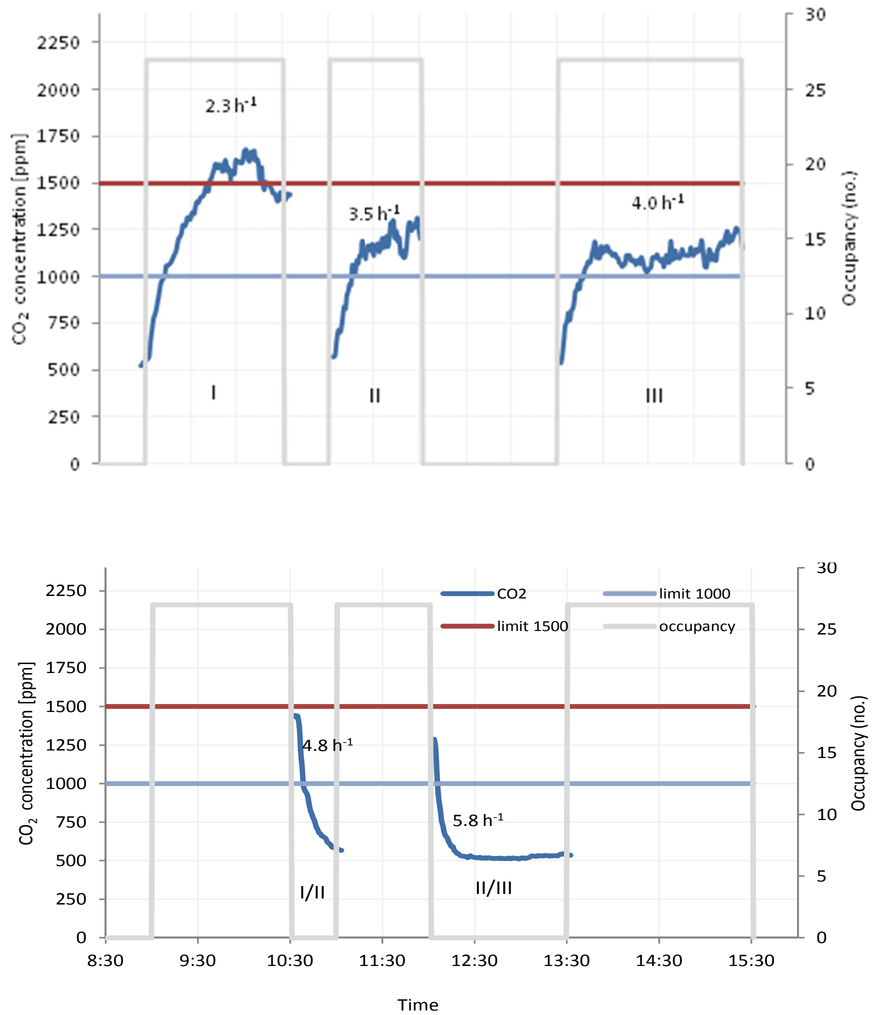
London has a mild marine climate that rarely shows extreme low or high temperatures. Ambient temperatures during the heating and non-heating seasons therefore fall in similar ranges. Lower temperatures in the classrooms were related to increased satisfaction with thermal comfort. Ventilation patterns in schools remained similar between seasons. In the UK, Building Bulletin 101 [110] provides the regulatory framework for the adequate provision of ventilation in schools based on Parts L and F of the Building Regulations, and recommends daily average concentrations of CO_2 below 1,500 ppm [8]. The majority of participating schools managed to comply with current UK IAQ recommendations, with the exception of one school with restricted windows for energy-saving reasons [45]. Higher levels of PM and total VOCs (TVOCs) were detected in kindergarten classrooms compared to primary school classrooms, indicating that younger children, who are more vulnerable, are exposed to higher pollution concentrations in the UK school environment. Concentrations of PM in classrooms were affected primarily by occupants' activities due to the re-suspension of previously deposited PM. Higher PM concentrations were recorded in winter in the majority of the classrooms. A larger fraction of PM dominated indoor concentrations during the non-heating season. Higher outdoor and indoor concentrations of NO_2 were measured during the heating season. However, the contribution to indoor concentrations (I/O ratio) was higher in the non-heating season. Lower wind speed and increased solar radiation resulted in higher outdoor concentrations of ozone in the non-heating season.

Ozone is highly reactive and may provoke ozone-initiated chemical reactions and transformations in indoor spaces (e.g. in the presence of high concentrations of terpenes, which may occur due to the use of some consumer products). Concentrations of TVOCs and VOCs were higher indoors than outdoors. Cleaning products and the timing of cleaning activities affected indoor concentrations of TVOCs and specific compounds detected indoors. Concentrations of compounds with indoor sources were higher where there were lower ventilation rates, while increased ventilation rates affected the indoor contribution of VOCs from outdoor sources. It is therefore essential to ensure that the broad range of construction materials and cleaning products used in classrooms do not seriously impact IAQ, even when ventilation rates fall below the requirements of existing ventilation standards. Deep cleaning to reduce dust reservoirs might reduce bacterial accumulation. Overall, the number of potentially pathogenic species was low, although the isolation of a few bacteria that may cause disease indicates a potential health risk to classroom occupants.

Effectiveness of natural ventilation in schools: the impact of different ventilation interventions

The main results of the pilot study are expressed in terms of the evolution of the CO_2 concentration. This report presents only the measurements obtained during one day of the measurement campaign (see annex 3.6). The CO_2 concentration evolved across the different periods of classroom occupation, following a path that is theoretically foreseeable both for the CO_2 build-up in the room during teaching time and for the lowering of the CO_2 concentration during breaks. The limits for the CO_2 evolution are reached when the concentration indoors is such that the ventilation rate is able to guarantee that the flow leaving the room removes all the instantaneous emissions from sources. The evolution of the concentration of CO_2 for a given specific space and occupation level is a function of the ventilation during the occupation periods and the breaks. Ventilation rates could be changed only through the "arranged" openings for the incoming air, since the air outlets were fixed and did not allow for any regulation.

Figure 47 shows the evolution of CO_2 for classroom occupation and break periods during the first day of the measurement campaign. The upper part of Figure 47 illustrates how the "arranged" openings (base case + All HW+CW1.1+CW3.1+CW3.2) proved to be effective for keeping CO_2 concentration levels below 1,500 ppm. The lower part of the figure shows the replicated effect of having CO_2 concentration levels reduced and reaching their background level after one hour.



Outdoor CO_2 concentration - 512 ppm

Figure 47. Evolution of CO_2 concentrations in a classroom during the second day of the measurement campaign

Higher PM concentrations were observed especially at the beginning and end of each class. A specific case of re-suspension due to indoor turbulence created by occupants' activities and movements was observed on the second day after 2.30 p.m. With respect to $PM_{2.5}$, since the classroom did not contain any specific PM emission source, concentrations were lower indoors than outdoors (I/O <1), indicating that they were likely to be mostly of outdoor origin with a limited contribution from indoor sources. Moreover, studies on source apportionment performed in Porto confirmed that the main source of pollutants, in particular of fine PM, is the outdoor air — that is, urban traffic.

Conclusions:

The CO_2 concentration in a classroom is a function of occupation density and activity, and of the level of ventilation. If clean materials are used in classrooms, and provided that the ambient air conforms to WHO guideline values, then the ventilation rate (in the case of both natural and/or mechanically assisted ventilation) can be established to properly control CO_2 levels based on the rate of CO_2 production by classroom occupants. It is possible, in particular in Cluster 4 countries (Southern Europe), to use natural ventilation to control CO_2 concentration levels in schools. The control of CO_2 in schools requires upstream considerations with respect to the design, location and construction of the building in order to ensure that the outdoor air respects WHO guidelines, and that inside the school building ventilation levels can be properly managed without negatively interfering with occupants' activities and performance and the concentration levels of air pollutants. However, at the design phase attention must also be paid to occupation density, as this will be the essential parameter for ensuring that a typically weak phenomenon such as natural ventilation is able to cope with and reduce the rate of produced CO_2 and other bio-effluents. A number of situations can be envisaged in which meteorological conditions may prevent windows from being opened (e.g. rain, wind, temperature). In such cases, it is possible to create the conditions of mechanically assisted ventilation using auxiliary mechanical systems to intensify the air renewal in the various spaces of the school building. When economically justifiable, mechanically assisted ventilation may include a heat exchanger to recover some of the heat energy transferred to the incoming air. One parameter that should not be neglected is the duration of both teaching periods and breaks. A judicious balance in their alternation and length will facilitate CO_2 control by passive or natural means.

The effectiveness of different mechanical ventilation systems: a comparison of different ventilation types

In general, this comparison indicated that the lowest levels of CO_2, $PM_{2.5}$ and TVOCs were monitored in the ventilated Class-1. The biggest difference between ventilated and aerated rooms was found in wintertime. In summertime, the classroom with the largest aeration surface (Class-3) had CO_2 levels that were comparable to those in the ventilated Class-1, while aeration through window opening led to CO_2 peak concentrations of up to 5,000 ppm in Class-2. While there were equal levels of CO_2 in Class-1 and Class-2 in summer, the highest levels of PM and TVOCs were monitored in Class-2.

The fact that classroom ventilation by window opening was discouraged in the event of colder outdoor temperatures is reflected in the average CO_2 levels during wintertime in Class-2 and Class-3, which were both approximately 2,000 ppm. The lowest CO_2 level in wintertime was registered in the ventilated Class-1 (870 ± 240 ppm). Relative humidity was comparable in summertime, but in wintertime the lowest average (below the guideline value of 30% contained in the Flemish Indoor Environment Decree) was found in Class-1, where it reached a minimum of 17% [21].

The lowest $PM_{2.5}$ concentrations and lowest PM_{10}/PM_1 ratio were found in Class-1, indicating the high level of efficiency of the ventilation system filters in removing the larger PM fractions from the intake air stream.

The SINPHONIE pilot study indicates that controlled ventilation is able to provide a solution to the issue of poor IAQ in Belgian classrooms. However, low wintertime relative humidity in the ventilated classroom should be considered with caution, since low relative humidity has been reported to be related to eye irritations [118] and may cause discomfort among classroom occupants.

4.7.2 Abatement and source identification studies in classroom environments

Measurement of the efficiency of an abatement measure to reduce indoor formaldehyde

Measurements of the efficiency of sorptive boards were performed in a controlled atmosphere of 100 µg/m³ formaldehyde [4], 50 µg/m³ toluene (average indoor level in 270 Flemish complaint-free houses, Belgium), 5 µg/m³ benzene (average indoor level in 270 Flemish complaint-free houses, Belgium), and 25 µg/m³ limonene (average indoor level in 270 Flemish complaint-free houses, Belgium) in a Belgian school building.

Table 27. Formaldehyde sorption flux of Material A and Material B

	Formaldehyde sorption flux, F_m ($\mu g.m^{-2}.h^{-1}$)					
	Day 1	Day 3	Day 7	Day 14	Day 28	Average
Material A [*active material*]	128.8	124.5	143.4	102.9	128.2	125.5
Material B [*equivalent non-active material*]	32.7	13.8	32.5	-16.3	13.0	15.2

Table 28. Formaldehyde equivalent ventilation rate of Material A and Material B

	Equivalent ventilation rate, FV,eq ($m^3.m^{-2}.h^{-1}$)					
	Day 1	Day 3	Day 7	Day 14	Day 28	Average
Material A [*active material*]	6.5	5.9	5.5	4.8	5.3	5.6
Material B [*equivalent non-active material*]	0.4	0.1	0.3	-0.2	0.1	0.2

Table 29. Formaldehyde reduction efficiency of Material A and Material B

	Formaldehyde reduction efficiency (%)					
	Day 1	Day 3	Day 7	Day 14	Day 28	Average
Material A [*active material*]	82	80	79	77	78	79
Material B [*equivalent non-active material*]	21	9	18	-12	8	9

The effectiveness of the active material used, compared to the non-active material, was studied by calculating the sorption flux, the equivalent ventilation rate and the total adsorbed mass. The results of this experiment (Tables 27, 28 and 29) show a substantial difference between the active material (Material A) and the traditional equivalent (non-active) material (Material B), which did not have formaldehyde-reduction properties. According to the simulations, Material A has an average formaldehyde reduction efficiency of 79%. This is in agreement with the product information communicated on the manufacturer's website. The difference compared to the normal, non-active material is noticeable.

An experiment carried out in a real-life chamber (MARIA[7]) confirmed the efficiency of the sorptive boards for formaldehyde reduction. After installing the boards the indoor concentration fell by 62%. When the boards were removed, the indoor formaldehyde concentration increased again. A similar tendency was observed for acetaldehyde, with a 60% decrease when the boards were installed, and an increase after their removal. For the two other aldehydes (benzaldehyde and hexaldehyde), a decrease in indoor concentrations of the same order of magnitude (60%) was observed. However, no increase (or just a slight increase in the case of hexaldehyde) was observed after the removal of the boards, which limits the possibility of identifying a relationship with the formaldehyde-reducing boards. Similar to the laboratory experiments, the formaldehyde-reducing boards seem to have no effect on VOCs, since the indoor concentrations in the room were stable over the three periods, except for formaldehyde in the indoor concentration of 2-ethylhexanol, which decreased after board installation but remained low after the board's removal. This evolution in the indoor concentration of 2-ethylhexanol might be attributable to other phenomena not linked to the experimental set-up.

The real-life experiment confirmed a formaldehyde reduction efficiency of 60% in the case of Material A installed in a room with a loading factor of 0.43 m^2/m^3.

Source identification experiments in classroom environments

Volatile organic compounds and aldehyde emissions were assessed for five products used in classrooms: a paint, a wooden game, crayons, a wooden kindergarten chair and a dry-erase marker. The paint, the wooden game and the crayons were tested at temperatures typically occurring in classroom environments in Southern Europe, while the kindergarten chair and the dry-erase marker were tested at typical Western European indoor temperatures. Both sufficient and insufficient classroom ventilation conditions were simulated. Using emission rates that were assessed by lab testing, air pollutant concentrations in classrooms related to the presence of the studied products were calculated, respecting the product amounts and the ventilation conditions typical for the classrooms. It was observed that the studied products were sources of VOCs in the classrooms, contributing to air pollution to different degrees. The tested liquid paints were the major contributors, emitting 1-ethoxy-2-propanol and benzyl alcohol in considerable concentrations after two hours of exposure. It should be noted that liquid paints are temporary pollution sources, and that children are exposed mainly while using them. However, even after the activity, the papers displayed on the classroom walls continued emitting chemicals, although at lower concentration levels. The varnished and glued chair also appeared to contribute to indoor VOCs and aldehyde emissions (highest emission rates for cyclohexanone, benzaldehyde and formaldehyde), especially when considered in the quantities in which they are typically installed in classrooms. The highest emission rates were determined 24 hours after installation. After three days the emission rates were lower, and they remained relatively unchanged five to six days after installation. The

[7] Experimental environmental house at CSTB (France).

tested wooden game, the dry-erase markers (with almost no emissions of volatile compounds after 24 hours) and the crayons were minor contributors to overall pollution. It can also be seen that the generated indoor concentrations in the high ventilation scenario were lower, as expected. However, it should be added that this is only true if the outdoor air is cleaner than the indoor air, which is in fact the commonly encountered situation.

Based on FLEC measurements in two schools (outcomes shown in Figures 48 and 49), it was observed that the contribution of building material emissions was significant in several cases and reached almost 40 to 50% of the WHO IAQ guideline values. Moreover, it is obvious that indoor levels of benzene originate mainly from outdoor sources, and in some cases from other unknown sources. The same results have also been found for public buildings investigated in the framework of the project Prioritization of Building Materials as Indoor Pollution Sources (BUMA) (http://www.uowm.gr/bumaproject/), where the emissions contributed from building materials reached up to 50% [78]. For better and more accurate results it is essential to have more measurements from more than one site and at different time intervals. Continuous IAQ measurements will also improve the methodology.

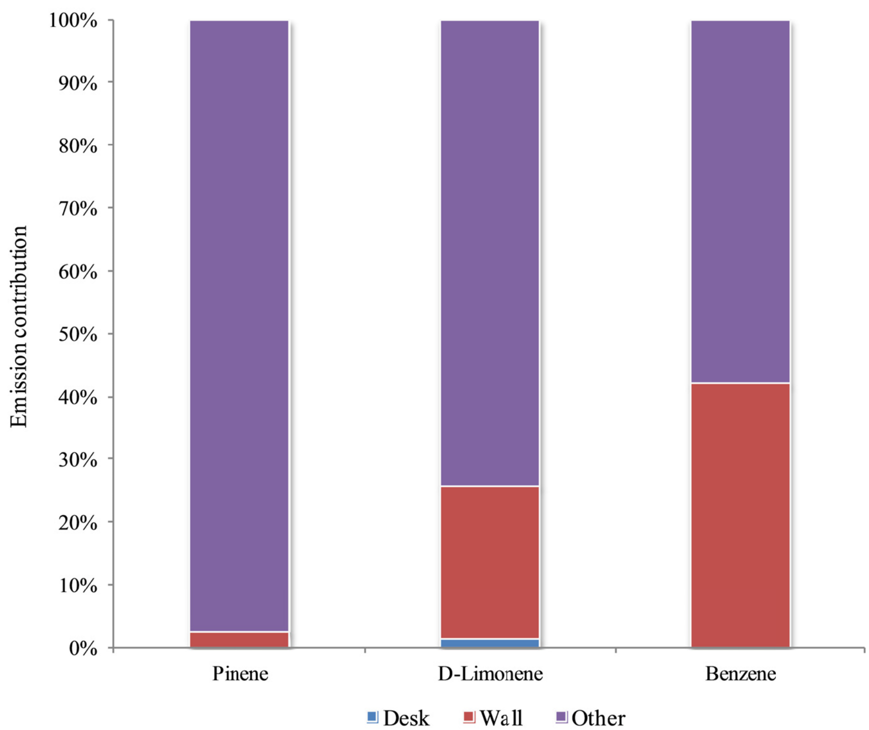


Figure 48. Contribution of building material emissions to IAQ in School-1 (GRS01R1)

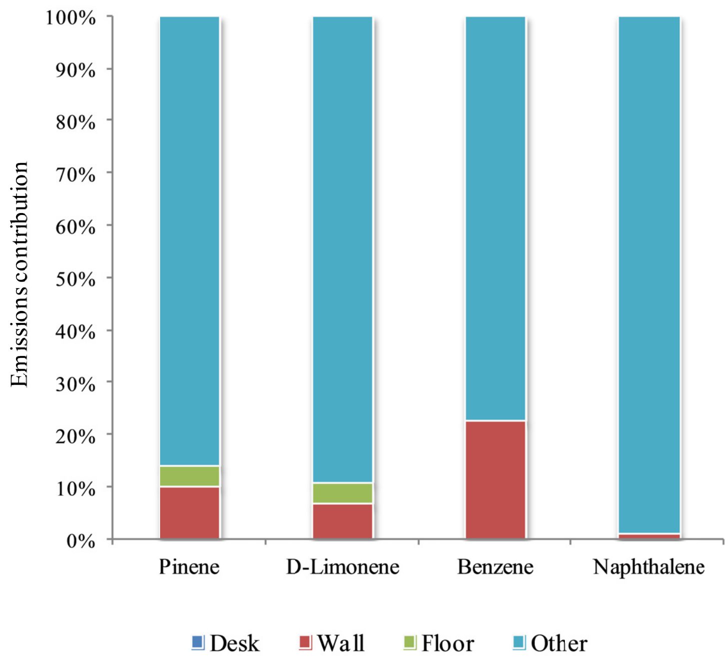


Figure 49. Contribution of building material emissions to IAQ in School-2 (GRS02R2)

4.8 Health effects among schoolchildren and teachers

4.8.1 Prevalence of symptoms and diseases

The prevalence of health outcomes was evaluated from the info collected by the SINPHONIE questionnaires (see Annex 4.1).

Prevalence rates of recent (<3 months) symptoms and diseases for SINPHONIE schoolchildren

Among all schoolchildren within SINPHONIE, the commonest recent (<3 months) health event was a blocked nose (47%) followed by a runny nose, feeling cold or feverish, headache, feeling tired and having a sore throat (36%). Table 30 also shows that 26% of children felt better on returning home. In the past year, the most frequent health event was nasal allergy (21%), followed closely by a night dry cough (19%). Runny nose ever, not occurring due to a cold (25%) and wheezing ever (23%) were very frequent. The prevalence of diagnosed asthma, nasal allergy and eczema was 8%, 9% and 17% respectively. More than 1% of children had had an asthma attack at school. Around 15% of children suffered from high stress at school. Symptoms and diseases varied among the countries. However, for all symptoms (or their improvement) there was no statistically significant difference between countries in terms of prevalence. These results are in line with those of the ISAAC Phase III study) [5], where the prevalence of asthma varied across the European centres from less than 5% to over 25%; rhinoconjunctivitis from less than 3% up to 20%; and eczema from 2% to over 20% in children between 6 and 7 years old [90]. In the HESE study, carried out in primary schools in five European countries, the reported prevalence of lifetime asthma was

16%, varying from 8% to 26% across the centres, in children aged between 9 and 10 years [95]. The SEARCH study, carried out in eight European countries among pupils aged between 9 and 14 years (mean age 11 years), showed a 10% prevalence of diagnosed asthma, a 28% prevalence of rhinitis and a 10% prevalence of eczema in the last 12 months [20]. The Italian SIDRIA2 study showed a 9% prevalence of asthma and a 27% prevalence of wheezing among children aged between 6 and 7 years old [95]. The prevalence of symptoms in the last 12 months was comparable with previously observed prevalence rates reported in international studies.

Prevalence rates of past-year symptoms and diseases for SINPHONIE schoolchildren

Among children at primary schools, parents reported a prevalence of 8% wheezing and 18% dry cough at night in the last 12 months (Table 31). Such prevalence rates are lower than those in the HESE study, where wheezing and night dry cough accounted for 13% and 34% respectively [43], but consistent with the SEARCH study results [20], which showed a prevalence of wheezing of about 13% and dry cough at night of 14% [33] and with the SIDRIA2 results, which reported an 8% prevalence of wheezing. The 17% prevalence of eczema in SINPHONIE children is also in line with the Italian results from the SIDRIA2 study (16%) [95, 39].

In general, the prevalence rates of past-year symptoms and diseases were lower among children in kindergartens compared to schoolchildren, apart from wheezing and night dry cough (17% *vs*. 8% and 26% *vs*. 18%, respectively) (Table 31).

Table 30. Prevalence of recent (<3 months) symptoms and diseases in children as reported by their parents

Prevalence (%) and 95% CI*									
Symptom/disease	Primary schoolchildren (N=4,919)			Kindergarten children (N=259)			All children		
Hand rash	6.8	6.0	7.5	9.0	5.6	12.4	6.9	6.2	7.6
Face rash	5.7	5.0	6.3	5.1	2.5	7.6	5.6	5.0	6.3
Eczema	7.1	6.3	7.8	6.7	3.8	9.7	7.0	6.3	7.7
Hand itch	8.8	8.0	9.6	8.6	5.2	11.9	8.8	8.0	9.6
Face itch	4.9	4.3	5.6	3.5	1.3	5.7	4.8	4.2	5.4
Eye irritation	13.4	12.4	14.3	10.2	6.6	13.8	13.2	12.2	14.1
Eye swelling	6.6	5.9	7.3	4.3	1.9	6.8	6.5	5.8	7.2
Headache	41.1	39.7	42.5	13.4	9.3	17.4	39.6	38.3	41.0
Nausea	17.8	16.7	18.9	10.7	7.0	14.5	17.5	16.4	18.5
Runny nose	42.0	40.1	43.4	50.4	44.7	56.1	42.5	41.1	43.8
Blocked nose	46.6	45.2	48.0	56.8	51.2	62.4	47.1	45.8	48.5
Dry throat	20.6	19.5	21.8	25.0	19.8	30.2	20.9	19.8	22.0
Sore throat	35.8	34.4	37.2	42.0	36.2	47.7	36.2	34.9	37.5
Feeling cold/feverish	41.2	39.8	42.6	44.5	38.6	50.4	41.3	40.0	42.7
Irritative cough	29.3	28.0	30.6	45.3	39.4	51.2	30.2	28.9	31.4
Shortness of breath	8.6	7.8	9.4	15.0	10.8	19.2	8.9	8.1	9.7
Feeling tired, out of sorts	36.2	34.8	37.5	29.8	25.0	34.6	35.8	34.5	37.1
Symptom(s) improve after returning home	25.9	24.4	27.4	33.2	26.8	39.5	26.2	24.8	27.7

*Pooled prevalence rates (%) ± 95% confidence interval using meta-analytic techniques (inverse variance–weighted method) for the participating countries

Table 31. Prevalence of symptoms and diseases in the past year and ever in children as reported by their parents

Prevalence (%) and 95% CI*

Symptom/disease	Primary schoolchildren (N=4,919)			Kindergarten children (N=259)			All children (N=1,200)			Teachers		
Wheeze (ever)	22.8	21.6	24.0	30.6	25.4	35.9	23.2	22.1	24.4	9.2	7.6	10.8
Wheeze (<12 months)	7.8	7.1	8.6	17.2	12.8	21.7	8.4	7.6	9.1	-	-	-
Wheeze (<30 days)	1.9	1.5	2.3	5.0	2.4	7.5	2.1	1.7	2.5			
Doctor-diagnosed asthma	7.6	6.9	8.4	6.3	3.4	9.2	7.6	6.9	8.3	8.8	7.3	10.4
Asthma in school	1.3	1.0	1.6	0.0	0.0	0.0	1.2	0.9	1.5			
Runny/blocked nose† (ever)	25.4	24.1	26.6	19.3	14.7	23.9	25.0	23.8	26.2			
Nasal allergy (ever)	13.4	12.5	14.4	7.7	4.4	10.9	13.2	12.3	14.1	26.5	24.1	28.9
Nasal allergy (<12 months)†	21.0	19.8	22.1	16.7	12.3	21.0	20.8	19.6	21.8			
Doctor-diagnosed nasal allergy	9.2	8.4	10.0	3.4	1.3	5.6	8.9	8.1	9.6			
Eye irritation (<12 months)†	8.4	7.6	9.2	5.7	3.0	8.4	8.2	7.5	9.0			
Itchy rash (for 6 months) (ever)	13.8	12.8	14.8	13.6	9.6	17.6	13.8	12.9	14.7			
Eczema (ever)	16.9	15.9	17.9	15.6	11.3	20.0	16.8	15.8	17.8			
Night dry cough (<12 months)	18.3	17.2	19.4	26.5	21.4	31.7	18.8	17.7	19.9			
Cough episodes	9.1	8.3	9.9	12.2	8.3	16.1	9.3	8.5	10.1			
Phlegm episodes	5.8	5.2	6.5	6.9	3.9	10.0	5.9	5.3	6.6	16.7	14.7	18.8

* Pooled prevalence rates (%) ± 95% confidence interval using meta-analytic techniques (inverse variance-weighted method) for the participating countries
† Not occurring due to a cold

Prevalence rates of past-year symptoms and diseases for SINPHONIE teachers

Among teachers, 27% had suffered from a nasal allergy in their life and 9% had asthma diagnosed by a doctor. Almost 17% of teachers had suffered from cough or phlegm (Table 31).

To our knowledge, no data are available for teachers' respiratory health in association with school-related environmental risks, therefore the SINPHONIE data represent new input concerning the health of this category of employees. Nonetheless, the prevalence of respiratory symptoms/diseases among teachers seems to be in line with the results of other studies among adults, when compared with sample data for the general adult population. In the European Community Respiratory Health Survey (ECRHS) study, which refers to adults aged between 20 and 44, the prevalence of diagnosed asthma ranged from 1% up to 13% (median 5%) [55], while the prevalence of reported wheezing at work was 10%, ranging from 4% to 15% [7].

4.8.2 Clinical assessments

For a range of clinical tests (assessments), the SINPHONIE project collected valuable and comparable data from a wide range of European countries.

Lung function

In order to control for the influence of age, height, weight (and weight squared) and gender, a linear regression was performed for each lung function parameter.

As expected, the end-expiratory flows (FEF_{50}, FEF_{75}) were subject to more pronounced inter-individual variation and therefore resulted in less accurate estimates of the regression coefficients. However, with the other parameters, highly significant regression coefficients could be calculated.

Table 32. Distributional statistics of lung function parameters

Variable	N	Mean	SD	Min	Max
$FEV_1{}^1$	4607	1.909663	0.4777794	0.18	5.28
FVC^1	4616	2.232156	0.5725513	0.35	6.57
Tiff	4607	86.27516	11.33977	5.20	101.52
PEF^2	4616	3.760877	1.11118	0.37	9.84
$FEF_{25}{}^2$	4220	3.481237	1.088674	0.11	9.83
$FEF_{50}{}^2$	4400	2.570940	0.8220153	0.08	9.17
$FEF_{75}{}^2$	4392	1.349772	0.5337948	0.03	5.09
$FEF_{25\text{-}75}{}^3$	3728	2.315541	0.6940697	0.17	6.87

SD: standard deviation; Min: minimum; Max: maximum; All data (including those rated as poor quality or poor collaboration) were included; ^{1} l; ^{2} $l.s^{-1}$; ^{3} $l.s^{-2}$

The data show sufficient variability and are from a sufficiently large number of children to allow further analyses regarding the possible environmental causes of the differences. Mean FEV_1 was 1.91 l, FVC 2.23 and the Tiffeneau (the FEV_1/FVC ratio) index 86% (Table 32).

In addition, the predicted FEV_1 percentile was 98.4 (±18.0) and the predicted FEF_{25-75} percentile 48 (±30.2). These values are comparable to those from previous population-based studies.

Rhinometry

Only Austria, Italy, Malta, Poland and Sweden performed rhinometry, and most of the participating partners were not very experienced with this technique. Figures 50, 51 and 52 show the rhinometry results in boxplots. Only one country (Poland) also performed rhinometry after decongestion. As a whole, mean rhinometry parameters did not differ significantly among countries.

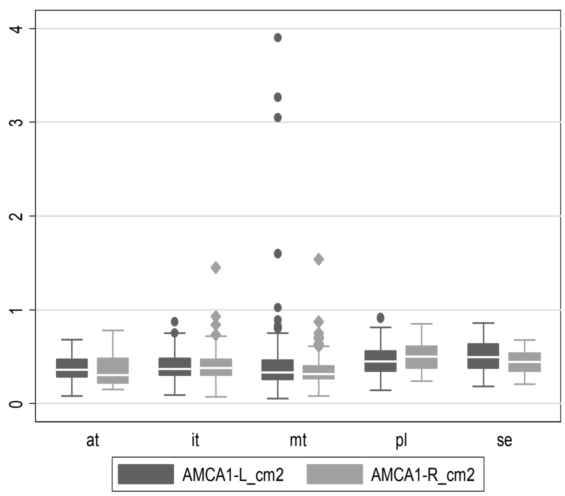


Figure 50. Boxplots of rhinometry results, left and right nose per country, diameter at first narrowing of the nasal canal

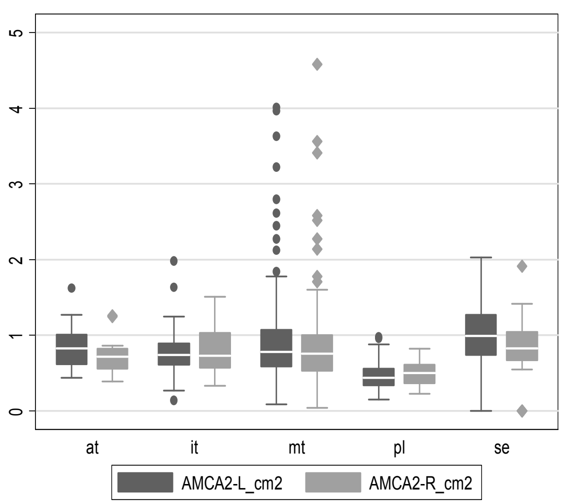


Figure 51. Boxplots of rhinometry results, left and right nose per country, diameter at second narrowing of the nasal canal

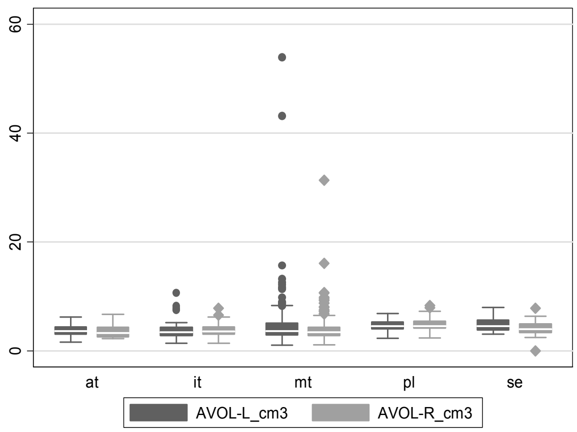


Figure 52. Boxplots of rhinometry results left and right nostril per country, nose volume (AVOL)

Fraction of exhaled NO

Exhaled NO was assessed by 11 SINPHONIE partners for a total of 744 schoolchildren. The limit of detection (LOD) of the method is given as 5 ppb. Only one partner (Finland) reported some children to have exhalded NO below the LOD, and these values are set to zero in this descriptive analysis. Although 9.7 ppb has been proposed as the reference value for normality in children, according to the ATS, airway inflammation exists with FeNO higher than 20 ppb. Almost 30% of children had FeNO higher than 20 ppb in the SINPHONIE study (Figure 53). The results can readily be compared between countries (Figure 54) and schools or classrooms. The variability is sufficient to study possible environmental influences.

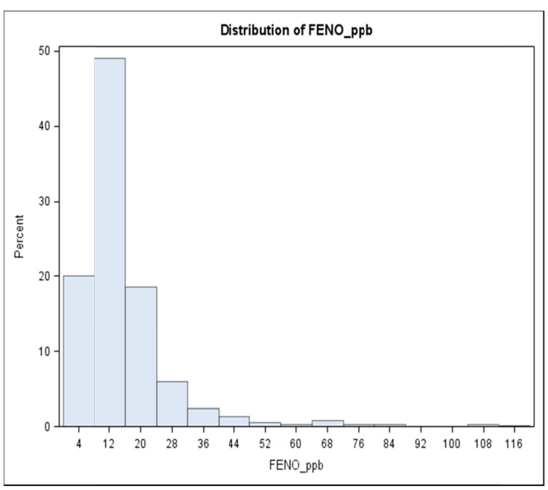


Figure 53. Distribution of FeNO

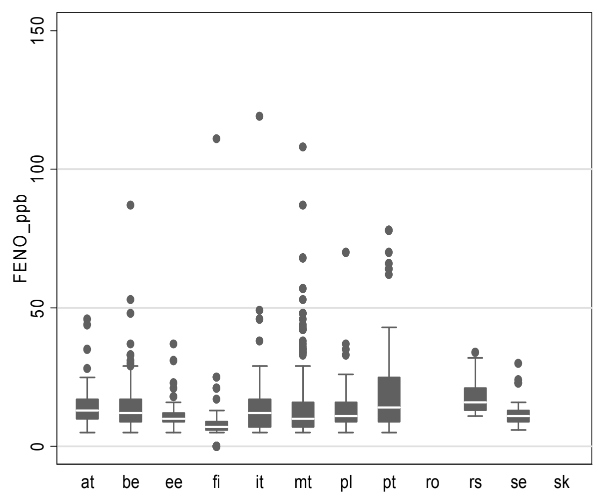


Figure 54. Boxplots of FeNO results per country

Skin prick test

Only a few SINPHONIE countries participated in the skin prick test, and not all of them analysed exactly the same set of allergens. It does not therefore make sense to compare country results for single allergens.

In total, 314 children from four countries (Italy, Poland, Portugal and Sweden) were examined. In all children there was no reaction to the saline negative control. The wheel diameter for the histamine positive control ranged from 2.5 to 10 mm (mean and median about 5 mm).

Positivity was defined as the maximal wheel diameter of all allergens tested. The diameter was calculated as the arithmetic mean of the largest and smallest diameter of each wheel. About 30% of children displayed a reaction to at least one of the allergens tested. In about 20% of children, this reaction was stronger than the reaction to the positive control (histamine).

Exhaled CO

Exhaled CO was only determined by Austria, Italy and Malta, and the results differ so greatly between these three countries that it can only be explained by the use of different methodologies that are not entirely comparable.

Tear break-up time

Tear break-up time was measured three times by most of the countries that performed the test. The Republic of Serbia reported only two consecutive break-up times per child. As can be seen from Figure 55, there was no clear trend from the first to the third taking of the test. It is therefore reasonable to use the mean over the three tests (two tests in the case of Serbia) for each individual child (Figure 56).

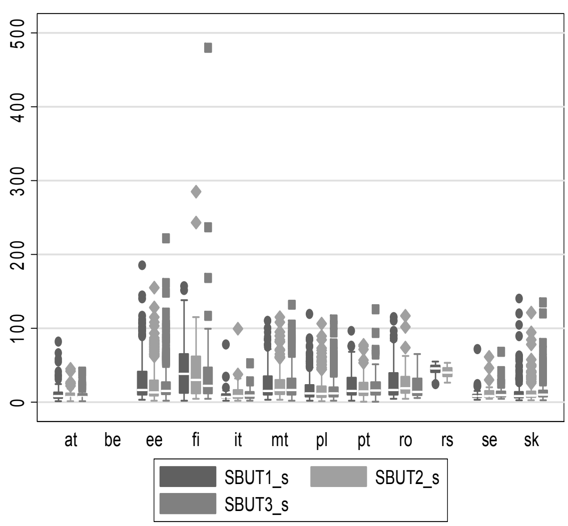


Figure 55. Boxplots of the break-up time results in three consecutive tests per child

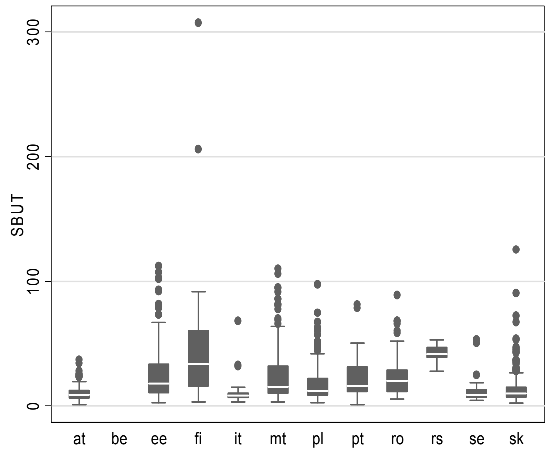


Figure 56. Boxplots of the break-up time results, mean across three consecutive tests per child

Stress

Among both primary schoolchildren (Figure 57) and kindergarten children (Figure 58), stress at school varied among countries.

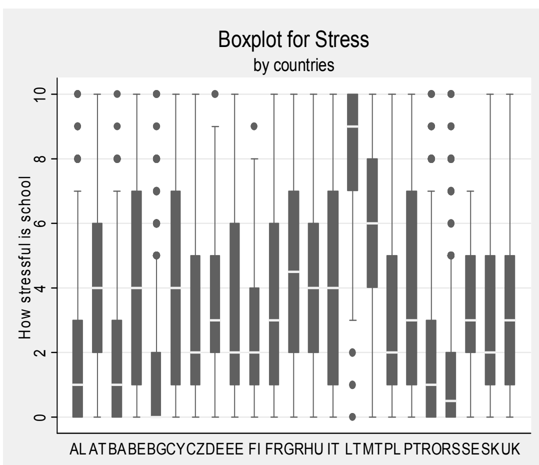


Figure 57. Stress at primary school among schoolchildren, reported by parents

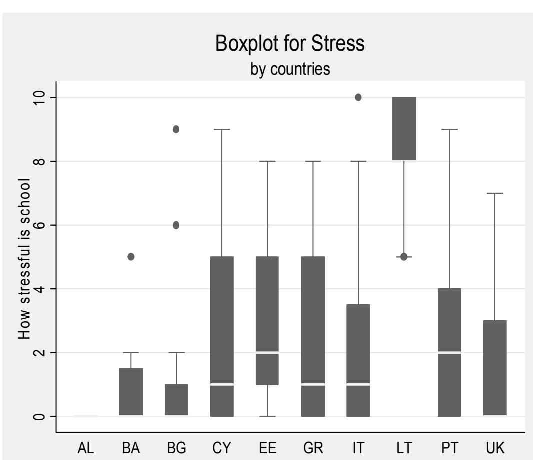


Figure 58. Stress at school among kindergarten children, reported by parents

In schoolchildren, stress at school was negatively related to CO_2, T4CE, Aalt cells and Myco cells. Among the covariates adjusted for, stress at school was associated (or showed a trend) with current exposure to smoking at home, a low level of maternal education, domestic pets and male gender, and inversely associated with living in Eastern Europe. Among kindergarten children, stress was positively related to high levels of formaldehydes and negatively to T4CE and Tviri cells.

Attention/concentration test

Altogether 12 of the SINPHONIE countries used the attention tests. A total of 2,909 children completed all four tests, while more of them completed one or another. In general, the mathematical test results were somewhat better in the morning than in the afternoon, while in the case of the logical tests the results of the second trial (at the end of the teaching hours) were significantly better than those of the first trial (2b-1b), which may be explained by the "learning effect" (Tables 33 and 34).

Table 33. Overall results of attention/concentration tests

	Score1a	Score1b	Score2a	Score2b	Diff 2a-1a	Diff 2b-1b
N	3080	3294	3062	3269	3055	3263
Mean	80.1	39.6	79.2	42.8	-0.83	3.24
Min	0	0	0	0	-68	-64.7
25^{th} percentile	69	29	68	31	-6	-2.52
Median	88	35.3	88	41	0	3.40
75^{th} percentile	97	46	96	50	4.16	10.09
Max	100	100	100	100	62.5	79

Min: minimum; Max: maximum;

There was no significant difference in the mathematical test results between the two genders, although the girls' logical test results were statistically significantly better than those of the boys, especially in the morning (p<0.001), even after adjusting for age.

The logical tests, performed either in the morning or in the afternoon, showed significant improvement with age. The mathematical test results also improved with age with the exception of the 11-year-old children, although this latter group consisted only of a relatively small number of children.

Both the mathematical and logical test results differed significantly among countries.

Table 34. Mean values of attention/concentration tests by gender, age and country

	N	Score1a	Score1b	Score2a	Score2b	Diff 2a-1a	Diff 2b-1b
Gender							
Boys	1483	80.2	38.4	79.1	41.9	-1.19	3.65
Girls	1426	79.9	39.9	79.3	42.8	-0.51	2.81
Age							
8 years	473	75.3	31.9	76.1	33.8	0.62	1.79
9 years	1079	80.7	38.2	80.3	42.3	-0.20	4.14
10 years	1003	82.5	41.4	80.5	44.6	-1.95	3.15
11 years	281	80.7	48.0	78.4	49.1	-2.25	1.29
Country							
AL	504	86.6	34.9	84.6	35.0	-2.0	0.82
BA	125	71.5	32.6	71.9	35.5	0.62	2.95
BE	107	65.6	33.8	64.5	44.1	-1.42	10.16
CZ	298	87.8	52.6	87.1	49.4	-0.74	-3.16
EE	188	85.9	73.2	85.3	77.9	-0.36	4.01
FR	234	77.6	41.8	74.1	46.6	-3.06	4.91
GR	95	27.5	50.4	29.0	57.6	1.60	7.37
HU	196	82.9	34.0	82.1	43.9	-0.26	9.97
IT	262	84.6	35.0	88.1	44.0	3.41	8.94
LT	218	88.0	45.1	88.7	49.5	0.68	4.38
PT	227	72.2	32.5	77.8	39.1	5.75	6.61
RS	495	79.5	28.7	73.8	25.5	-5.69	-3.19

Absenteeism

Table 35. Percentage of absent children per day per class and by country

	N	Mean	SD	Min	25th percentile	Median	75th percentile	Max
AL	18	1.77	1.26	0.15	0.92	1.48	2.36	4.34
AT	9	3.43	1.80	0.80	2.46	3.37	3.86	7.27
BA	12	4.88	4.55	1.08	2.37	3.41	5.26	17.5
BE	4	5.66	2.26	3.76	4.21	4.98	7.10	8.91
BG	15	7.79	4.89	1.32	4.27	6.90	13.24	16.75
EE	14	8.65	2.65	3.05	6.85	9.22	10.40	13.03
FR	10	3.40	2.00	0.65	2.11	3.05	4.51	7.84
GR	6	5.70	1.86	3.51	4.69	5.28	6.54	8.88
HU	18	4.56	0.93	3.42	3.45	4.49	5.11	6.11
IT	17	10.07	6.52	3.80	6.19	7.01	11.00	27.52
LT	15	12.43	12.48	2.23	3.49	8.46	13.59	45.44
PL	15	7.01	2.54	4.07	4.80	6.83	8.29	12.79
PT	15	2.85	4.03	0.00	0.30	1.15	3.24	15.32
RO	15	2.44	1.94	0.00	0.91	1.32	4.77	5.34
RS	15	1.30	0.94	0.66	0.88	1.13	1.75	2.54
SK	4	11.44	4.81	6.99	8.11	10.32	14.77	18.12
Total	202	5.64	5.65	0.00	2.22	4.45	7.33	45.44

N: number of classrooms; SD: standard deviation; Min: minimum; Max: maximum

In order to include as many classrooms as possible, the statistical evaluation was undertaken at class level. Absenteeism was evaluated for a total of 202 classrooms from 16 countries within SINPHONIE. Two parameters were evaluated: 1) percentage of absent children per day per classroom; and 2) percentage of days with any absenteeism per class. The descriptive results of these two parameters are presented in Tables 35 and 36.

Table 36. Percentage of days with any absenteeism per class, by country

	N	Mean	SD	Min	25th percentile	Median	75th percentile	Max
AL	18	29.30	19.62	2.53	17.72	25.32	37.50	65.82
AT	9	45.81	18.35	17.54	38.60	47.37	51.85	72.73
BA	12	55.68	24.97	23.44	40.29	49.11	72.87	96.88
BE	4	69.64	7.04	61.29	64.97	69.40	74.31	78.46
BG	15	61.04	28.08	18.06	35.21	56.34	93.18	100.00
EE	14	59.61	20.82	34.18	39.24	57.59	73.33	93.10
FR	10	49.81	20.05	16.98	32.08	51.89	60.38	84.91
GR	6	54.96	19.02	26.98	43.06	54.86	70.83	79.17
HU	18	60.17	7.19	46.99	56.63	58.43	65.06	75.90
IT	17	76.00	15.16	37.50	71.23	77.78	84.72	98.59
LT	15	71.90	25.79	25.68	43.48	80.88	92.54	100.00
PL	15	63.62	15.78	38.57	51.43	67.14	75.71	91.43
PT	15	32.10	28.34	0.00	7.69	19.23	53.42	98.72
RO	15	31.88	18.71	0.00	16.44	31.51	46.57	60.27
RS	15	20.09	5.83	11.84	14.47	21.05	23.68	32.89
SK	4	80.71	10.47	72.86	73.57	77.14	87.86	95.71
Total	202	51.76	25.95	0.00	30.38	53.22	71.67	100.00

N: number of classrooms; SD: standard deviation; Min: minimum; Max: maximum

4.9 Health outcomes and indoor exposure

4.9.1 Chemical parameters and reported health outcomes

Several air pollutants were significantly related to the considered health outcomes in children and teachers (Table 37). Recent (<3 months) symptoms were more often related than symptoms in the past year or ever.

Formaldehyde in classrooms was significantly related to recent hand and face itching, dry throat, itchy rash and eczema (ever), nasal allergy and phlegm in children. Formaldehyde has rarely been measured in schools. Only 12 studies out of the 45 presented in the review conducted in the framework of SINPHONIE included this air pollutant. In these studies, formaldehyde exposure was measured using different methods. Significant associations between formaldehyde concentrations and health were found in five studies [3, 81, 102, 104, 127]; two others did not show any statistically significant association; and four papers did not investigate this link. Formaldehyde has been related to nocturnal attacks of breathlessness and cumulative asthma overall in non-allergic children [127]. Higher concentrations of this pollutant were associated with decreased nasal patency [83] and new asthma diagnosis among children without a history of atopy [102]. In the French six-city study, which covered 108 schools, formaldehyde was related to an increased risk of rhinitis [3]. Formaldehyde has also been related to headaches [116].

Benzene, naphthalene, limonene, T3CE and T4CE have been related to irritation symptoms in several parts of the body and to nasal allergy and wheezing in children. The health effects of exposure in classrooms to these air pollutants have not been investigated so far. However, exposure to benzene has been associated with asthma in schoolchildren, in whom SPMA, a biomarker of benzene, was also associated with asthma [90].

In addition, VOCs in schools have been linked to allergic and respiratory health. Current asthma risk was increased by 1.3 with an increase of 10 $\mu g/m^3$ in VOCs concentrations in Smedje et al. [104]. In Norbäck et al., concentrations of VOCs and aromatic n-alkanes, terpenes and butanols were correlated with the prevalence of chronic symptoms. In addition, TVOCs concentration was related to chronic airway, chronic general and chronic eye symptoms [35]. Exposure to aldehydes was found to be associated with airway inflammation, as measured by FeNO, in schoolchildren in the French six-city study [3]. Differences between high and low exposure in non-asthmatics resulted in an FeNO increase, ranging from 45% for indoor acetaldehyde in the classrooms [35]. These associations occurred even in children with no history of airway damage and seem to be enhanced in atopic subjects.

Nitrogen dioxide has been associated with recent hand rash, itchy rash, face eczema, feeling cold and irritative cough. Nitrogen dioxide has already been associated with respiratory and allergic health in the literature. A 10 $\mu g/m^3$ increase in indoor concentrations of this pollutant has been associated with current asthma, asthma attacks and asthma medication [73]. In addition, the outdoor concentrations were linked to current asthma, and indoor/outdoor ratios to current wheezing and asthma attacks. In the French six-city study, Annesi-Maesano and colleagues [3] also found associations with current atopic dermatitis both at school (schoolyards) and city level. The level of NO_2 in classrooms was also related to past-year asthma overall in allergic children in this study [3]. Finally, Castro et al. [13] found that NO_2 was related to decreased lung function. Other studies have found significant NO_2 effects on health [127] and particularly on lung function [15, 94]. Persuasive evidence links higher indoor concentrations of NO_2 to reduced school attendance, and suggestive evidence links low ventilation rates to reduced performance, primarily through health effects from indoor pollutants [76].

The presence of $PM_{2.5}$ in classrooms in primary schools has been related to recent irritative cough, runny nose, eczema, headache and nausea in children and to cough and phlegm in teachers. Although PM has been linked to various health outcomes, links between health and $PM_{2.5}$ concentrations in schools have only been described in Annesi-Maesano et al. [2, 3]. Significant associations between $PM_{2.5}$ and premature death in adults were reported by WHO [123]. After adjustment for confounders and NO_2 as a potential modifier, the odds of suffering from exercise-induced asthma and flexural dermatitis at the time of the survey, past-year atopic asthma and skin prick test positivity to indoor allergens were significantly increased in schoolchildren whose schoolyards presented $PM_{2.5}$ concentrations exceeding 10 $\mu g/m^3$ (WHO air quality limit values) [12]. Similar values were found when considering the concentrations of $PM_{2.5}$ in the schoolyard [3]. In this same population, airway inflammation, as assessed by levels of FeNO, was significantly elevated in both asthmatic and non-asthmatic children exposed to high concentrations of $PM_{2.5}$ [35]. Differences between high and low exposure in non-asthmatics resulted in a FeNO increase in the range of 62% for indoor $PM_{2.5}$.

Ozone in classrooms has been related to sore throat, irritative cough in children and asthma in teachers. Zhao et al. [127] found that this pollutant in schools was linked to an increase in nocturnal attacks of breathlessness in children. Another negative effect was found on lung function in Castro et al. [13]. However, Chen et al. [15] found that ozone was associated with a decrease in lung function that can occur at peak hourly ozone concentrations of < 80 ppb (160 $\mu g/m^3$). The slope of lung function decrease was approximately 1 ml/ppb for peak hourly ozone exposure. Ozone was also implicated in absenteeism at school. Romieu et al. [92] found that the more children were exposed to ozone, the greater the risk of absenteeism.

No associations were found between CO exposure in classrooms and the respiratory health of schoolchildren.

Symptoms improved on returning home when they were significantly related to limonene, PM2.5 and ozone in schoolchildren and to PM2.5 among kindergarten children.

4.9.2 Microbiological agents and reported health outcomes

There are a very limited number of reports that have explored the association between microbial exposure in schools and impacts on respiratory health. Both positive and negative associations between microbial levels and respiratory symptoms have been reported. A study in Swedish schools [65] reported the protective effects of microbial exposure (muramic acid, ergosterol) on asthma symptoms; the effect of endotoxin (lipopolysaccharide, LPS) was not clear and was found to be dependent on the chain length of the fatty acids within the LPS molecules. On the other hand, *Aspergillus versicolor* and *Streptomyces* spp., measured via qPCR, were found to be associated with respiratory symptoms in Swedish schoolchildren [102]. Another study in five European countries found inverse associations between these microbes in floor dust and lung function. *A. versicolor* was, in addition, associated with wheezing, rhinitis and coughing in schoolchildren in the same study [74].

The selection of the microbial agents measured in SINPHONIE was based on previous knowledge of the suggested adverse health effects of the target compounds and/or their link to indoor conditions of moisture damage and dampness. Endotoxin is a known inflammatory agent and respiratory irritant and has been targeted in many home studies on asthma and allergy — with contradictory findings. The timing of exposure to endotoxin (e.g. in early childhood versus later in life), in addition to the level and duration of exposure, seem to be highly relevant for either the protective or adverse effects of endotoxin on human health. Endotoxin in Dutch schoolchildren has been linked to asthma-like symptoms in a recent study [54]. In SINPHONIE, irritation symptoms in schoolchildren and kindergarten children were linked to elevated levels of endotoxin. Moreover, doctor-diagnosed asthma, runny/blocked nose ever, nasal allergy and cough symptoms were linked to high endotoxin in schools, although all these observations were made only in pupils, and not in teachers.

Among the fungal species/groups targeted, the *Penicillium/Aspergillus/Paecilomyces* group, *Aspergillus versicolor* and *Trichoderma viride* were assayed because of their potential link to moisture damage conditions, as well as due to suggested adverse effects on respiratory health. *Alternaria alternata* and *Cladosporium herbarum* have a strong outdoor context and are known for their allergenic properties. In schoolchildren, no clear trends towards adverse health impacts were seen for any of these targets, although protective effects were observed. An exception was *Aspergillus versicolor,* which was linked to sore throats and feeling cold/feverish among schoolchildren. In teachers, *A.versicolor* was linked to wheezing and cough episodes. Interestingly, *Alternaria alternata* showed significant associations — in teachers — to wheezing and asthma in the last 12 months, and was linked to elevated levels of FeNO, a marker of airway inflammation.

An overview of health outcomes in schoolchildren and teachers significantly associated with various microbial agents in SINPHONIE (Tables 37 and 38). Results persisted after adjustment for potential confounders.

Table 37. Relationships between chemical parameters and health outcomes in children and teachers

	Schoolchildren	**Kindergarten children**	**Teachers**
Formaldehyde	Hand itching, face itching, blocked nose Night dry cough (<12 months)	Dry throat Nasal allergy (<12 m), itchy rash (ever) (for 6 months), eczema (ever) Phlegm episodes	-
Benzene	Hand itching, recent eczema Eczema (ever)	Runny nose, sore throat, recent eczema	-
Naphthalene	Face itching, feeling tired and out of sorts	-	Nasal allergy
Limonene	Eye irritation, runny nose, blocked nose, sore throat, irritative cough, feeling cold/feverish, eczema, nausea, feeling tired and out of sorts Eye irritation (<12 months), eczema (ever) Symptoms improve on returning home	-	-
T3CE	Hand rash, hand itching, face itching, swollen eyes,	Eye irritation Nasal allergy (<12 months), wheezing	Cough/phlegm episodes

	headache, sore throat, feeling tired, feeling cold/feverish	(<12 months)	
T4CE	Hand itching, sore throat, wheezing (<30 days), nasal allergy (<12 months)	Sore throat	
NO2	Hand itching, face rash, recent eczema, feeling cold/feverish	Irritative cough	
PM2,5	Dry throat, nausea Symptoms improve on returning home	Runny nose, recent eczema, headache	Cough/phlegm episodes; Symptoms improve on returning home
Ozone	Feeling tired and out of sorts Wheezing (ever), runny/blocked nose (ever) Nasal allergy (<12 months), doctor-diagnosed nasal allergy, itchy rash (for 6 months) (ever), asthma in school Symptoms improve on returning home	Sore throat, irritative cough	Doctor-diagnosed asthma, asthma (ever)

T3CE: trichloroethylene; T4CE: tetrachloroethylene

Table 38. Relationships between microbiological contaminants and health outcomes in children and teachers ("↓" indicates inverse associations)

	Schoolchildren	**Kindergarten children**	**Teachers**
Endotoxin	Eye irritation, dry throat, irritative cough Doctor-diagnosed asthma, runny/blocked nose (ever), nasal allergy, night dry cough, cough episodes	Hand rash, eye irritation Phlegm episodes	
Fungal species/groups			
Penicillium/ Aspergillus/ Paecilomyces spp.Group	Symptoms improve on returning home Nasal allergy (ever) (↓)		
Aspergillus versicolor	Sore throat, feeling cold/feverish		Wheezing, cough/phlegm episodes
Trichoderma viride		Runny/blocked nose (ever) (↓), nasal allergy (↓)	
Alternaria alternata	Eye irritation (↓)	Symptoms improve on returning home (↓)	Wheezing, asthma (<12months) FeNO
Cladosporium herbarum		Phlegm episodes	
Bacterial groups			
Streptomyces spp.		Irritative cough	Wheezing, cough/phlegm episodes
Mycobacterium spp.	Runny/blocked nose (ever)	Runny nose, dry throat	

The targeted bacterial groups are commonly encountered in the environment. They are linked to moisture damage conditions indoors and are potential bioactive agents, making them potential candidates to explain adverse health effects observed in residents of damp buildings. In SINPHONIE, runny nose, irritative cough and dry throat in schoolchildren and kindergarten children were linked to these bacterial genera. Elevated levels of *Streptomyces* spp. in dust were linked to wheezing and cough/phlegm episodes in teachers.

In summary, multiple associations between selected microbial agents in indoor dust in schools and recent symptoms, past respiratory health symptoms and clinical measurements were shown in SINPHONIE, indicating the relevance of microbial agents to the respiratory health of pupils and teachers. Interestingly, the microbial agents seemed to have different effects, depending on whether pupils or teachers were exposed. Even though not investigated in SINPHONIE, it is likely that the school environment contributes considerably to the total burden of microbial exposure in pupils and teachers. In the case of endotoxin, it has been shown in recent studies that exposure levels in classrooms are far higher than in the home environment. It is very plausible that a similar trend can also be seen for some of the other microbial exposures assessed in SINPHONIE.

4.9.3 Chemical parameters, microbiological agents and clinical tests

Few significant relationships were found between chemical air pollutants and lung function parameters in schoolchildren. Ozone (p=0.021) and T4CE (p=0.036) were significantly associated with a decrease of FEV_1 (% of predicted). Ozone (p=0.005) was significantly associated with a decrease of $FEV_{25\text{-}75}$. Limonene (p=0.030) was inversely associated with a decrease of $FEV_{25\text{-}75}$. The Tiffeneau index, which is not as pertinent for children, was inversely associated with the concentration of benzene in classrooms. No association was observed between lung function parameters and bio-contaminants.

Fractional FeNO significantly increased with T3CE and Aaltr cells. The tear break-up time increased in schoolchildren in classrooms with elevated concentrations of T3CE, T4CE and CO_2.

No other significant relationships were found between chemical air pollutants and bio-contaminants on the one hand, and the other clinical tests on the other.

4.9.4 Building characteristics, comfort parameters and health outcomes

The SINPHONIE study did not show any particular link between temperature and relative humidity and health outcomes in children or teachers. An increase in temperature in classrooms has been related elsewhere to a risk of daytime breathlessness of 1.26 [77], while Smedje et al. [103] found a protective effect on current asthma. Classroom temperature was also linked to absenteeism due to respiratory illness in Romieu et al. [92]. The risk of absenteeism was 1.28 times higher in the case of high exposure compared with low-exposed subjects. Relative humidity in schools has been associated in two studies with current asthma. In the case of an increase of 10% in relative humidity, the risk of current asthma increased by 1.3 and 1.8 [77, 104]. Koskinen et al. [69] showed that in day-care centres with mould problems, overall morbidity in terms of respiratory symptoms and the common cold increased compared with the reference day-care centres.

Only a few studies have investigated the associations between CO_2 and health. Levels of CO_2 have been positively associated with asthma attacks, asthma medication and current asthma [74], as well as with dry cough at night and rhinitis [97]. Protective effects have also been found for nocturnal and daytime breathlessness [5, 77]. In addition to respiratory health, high CO_2 concentrations were linked in Shendell et al. [97] to absenteeism. In a review of the influence of indoor pollution and thermal conditions on student performance, higher indoor CO_2 concentrations were associated with lower scores on computerised tests of reaction times and neurological symptoms [76].

The health status of children participating in the SINPHONIE project was assessed by several means: one questionnaire was completed by the parents, another by the pupils themselves, and the children's absenteeism and attention capacity were also evaluated. Classroom characteristics, including the ventilation regime and cleaning activities, were assessed by a classroom questionnaire completed by the teachers.

Table 39. Adverse relationships between building characteristics, maintenance and operation and children's health

Building characteristics, maintenance and operation	**Significant crude association with**	**Significant adjusted# association with**
Occupation density ($<1.5m^2$/child)	Asthma attack in the classroom Headache at school, past 7 days Tiredness at school, past 7 days	Asthma attack in the classroom
Plastic floor in the classroom	Sneezing, past 12 months Blocked/runny nose, past 12 months Diagnosed allergic rhinitis Diagnosed allergy to dogs, cats, pollen Dry cough at school, past 7 days Sore throat, past 7 days Fatigue, past 7 days	Sneezing, past 12 months Blocked/runny nose, past 12 months Diagnosed allergic rhinitis Diagnosed allergy to cats and pollen Dry cough at school, past 7 days Sore throat, past 7 days Fatigue, past 7 days
Classroom wall painted with water-soluble paints	Asthma attack ever at school Skin rash on hands or forearms, past 3 months Itching hand or forearms, past 3 months Diagnosed allergic rhinitis Diagnosed allergy to cats (especially if painted within one year) Breathing difficulties at school in the past 7 days Attention	Asthma attack ever at school Skin rash on hands or forearms, past 3 months Itching hand or forearms, past 3 months Breathing difficulties at school, past 7 days Diagnosed allergy to cats (especially if painted within one year) Attention
Classroom wall painted with water-resistant paints	Attention	Attention
Classroom wall whitewashed	Feeling of getting a cold	Feeling of getting a cold
Classroom walls covered with wallpaper	Earache (otitis), past 12 months Tiredness, past 3 months Absenteeism	Earache (otitis), past 12 months Tiredness, past 3 months Absenteeism

Adjusted for age, gender, maternal education, environmental tobacco smoke and country

Statistically significant adverse relationships between building characteristics, maintenance and operation and children's health are summarised in Table 39. In some cases, the association is obvious (e.g. wheezing at school in classrooms with a mouldy odour), while in other cases the association needs further investigation. It is important to stress that statistically significant associations do not necessarily mean causal relationships, although they help to generate hypotheses or direct attention to possible background associations.

Table 39. Adverse relationships between building characteristics, maintenance and operation and children's health (cont.)

Building characteristics, maintenance and operation	Significant crude association with	Significant adjusted# association with
Cleaning the classroom in the evening	Runny nose, last 3 month Phlegm, last 3 months Tiredness, last 3 months	Runny nose, last 3 month Phlegm, last 3 months Tiredness, last 3 months
Cleaning the classroom in the morning	Dry cough at school, past 7 days	Dry cough at school, past week
Vacuum cleaner used for classroom cleaning	Itching or irritated nose at school, past 7 days Stuffy or blocked nose at school, past 7 days Sneezing at school, past 7 days Bleeding nose at school, past 7 days Dry throat at school, past 7 days Headache at school, past 7 days Fatigue at school, past 7 days Wheezing at school, past 7 days Absenteeism Itching eyes, past 7 days	Itching or irritated nose at school, past 7 days Stuffy or blocked nose at school, past 7 days Sneezing at school, past 7 days Bleeding nose at school, past 7 days Dry throat at school, past week Headache at school, past 7 days Fatigue at school, past 7 days Wheezing at school, past 7 days Absenteeism
Mop used for classroom cleaning	Eczema, past 3 months Food allergy confirmed by a doctor Skin rash on hand or forearms at school, past 7 days Dry throat at school, past 7 days Asthma attack at school, ever	Eczema, past 3 months Food allergy confirmed by a doctor Skin rash on hand or forearms at school, past 7 days Dry throat at school, past week Asthma attack at school, ever
Windows closed during cleaning	Wheezing at school, ever Difficulty breathing at school, past week Dry throat at school, past 7 days Sensation of sand in eyes at school, past 7 days	Wheezing at school, ever Difficulty breathing at school, past week Dry throat at school, past week Sensation of sand in eyes at school, past 7 days

Adjusted for age, gender, maternal education, environmental tobacco smoke and country

Table 39. Adverse relationships between building characteristics, maintenance and operation and children's health (cont.)

Building characteristics, maintenance and operation	Significant crude association with	Significant adjusted# association with
Classroom furniture installed within one year	Nasal allergy confirmed by a doctor Allergy to cats confirmed by a doctor Eczema, last 3 months	Allergy to cats confirmed by a doctor Asthma attack at school, ever Stuffy/blocked nose at school, past 7 days Difficulty breathing at school, past 7 days
Blackboard with chalk	Doctor-diagnosed allergic rhinitis Allergy to cats confirmed by a doctor Eczema, ever	Doctor-diagnosed allergic rhinitis Allergy to cats confirmed by a doctor
Use of products with irritant smell	Sore throat at school, past week Dry cough at school, past week	Sore throat at school, past week Dry cough at school, past week
Classroom with mouldy odour	Wheezing, ever Wheezing at school, past week	Wheezing, ever Wheezing at school, past week
Higher (>1) floor levels	Sneezing at school, past 7 days Bleeding nose at school, past 7 days	Sneezing at school, past 7 days Bleeding nose at school, past 7 days
Classroom facing the street	Allergy to dogs confirmed by a doctor Cough with phlegm on most days of the week Feeling tired during the last 3 months Nasal allergy confirmed by a doctor Allergy to cats confirmed by a doctor Allergy to food confirmed by a doctor	Allergy to dogs confirmed by a doctor
Air conditioning in the classroom	Pollen allergy diagnosed by a doctor Allergy to cats, confirmed by a doctor Food allergy confirmed by a doctor Itchy rash during the past 12 months	Pollen allergy diagnosed by a doctor

Adjusted for age, gender, maternal education, environmental tobacco smoke and country

Some associations were found that illustrate the possible relationships between building characteristics, maintenance and operation, and children's health (Figures 59, 60 and 61).

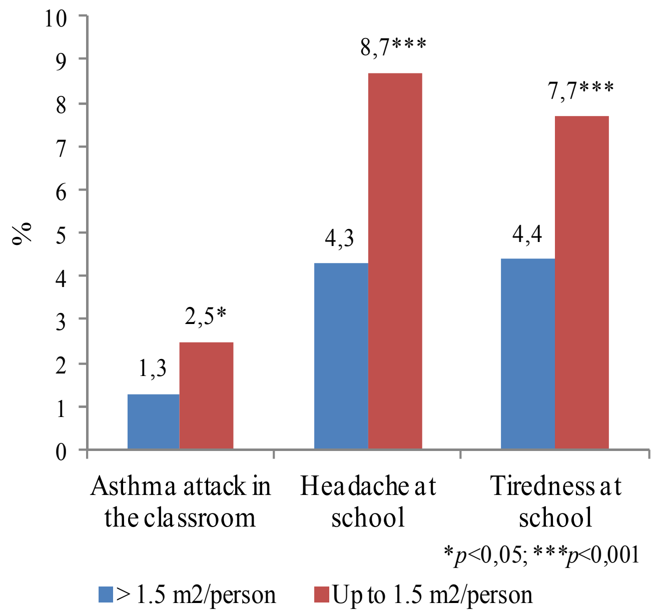


Figure 59. Association between the prevalence of children with health symptoms in the classroom and occupation density

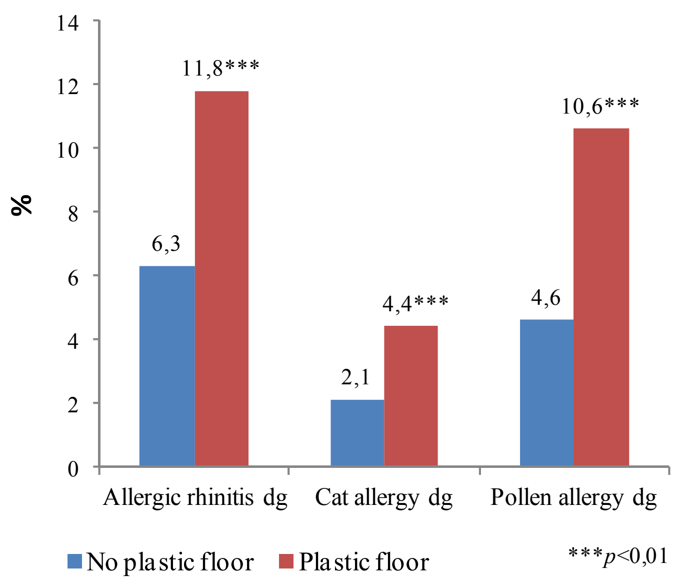


Figure 60. Association between the prevalence of children with doctor-diagnosed allergies and plastic floor covering

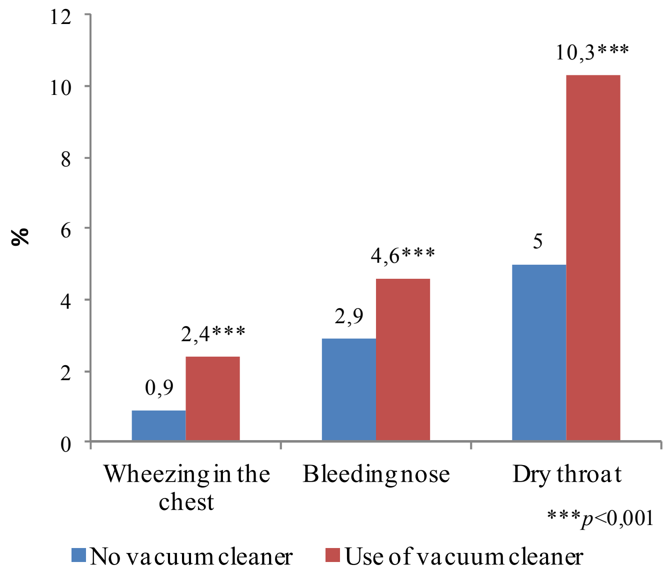


Figure 61. Association between the prevalence of children with health symptoms at school in the past week and the use of vacuum cleaners

Various school characteristics and their impacts on schoolchildren's health have been reported. Ventilation is an essential element of IAQ because it allows for the diluting of the pollution load. Poor ventilation rates, air exchanges and airflows inside schools, causing increased CO_2 levels in classrooms, are quite common throughout Europe. Poor ventilation (air exchange rate ≤0.68/h, airflow ≤1.8 l/s.p) has been related to the following symptoms and complaints: current asthma [102], mucosal irritation [103], reduced ability to concentrate, dizziness, dry, itchy or irritated skin on the face and hands, dry or irritated throat, dry, irritated or itchy eyes, headache, pain in the neck or shoulders, hoarseness or pain in the throat (only significant change), runny nose, and dry, irritated or stuffy nose. The decongestive effect of xylometazoline has also been noted [113]. Walinder et al. [114] show that indoor concentrations of VOCs, bacteria and mould were more frequently encountered, and at higher levels, in schools with low ventilation rates compared to those with high ventilation rates. The same authors suggest that raised levels of indoor pollutants due to inadequate ventilation may affect the upper airways and cause a swelling of the nasal mucosa and increased lavage levels of eosinophilic cationic protein and lysozyme in occupants, as compared with schools with natural ventilation only. Ventilation can also have a positive impact on children's health. Smedje et al. [103] have demonstrated the beneficial effects of a new ventilation system on asthmatic symptoms. It has been shown that the renovation of schools to obtain a ventilation rate of 9 l/s (to remain under 1,000 ppm CO_2) led to a significant reduction in general symptoms [79]. In addition, different types of ventilation, for example mechanical or natural, can have a different effect on health. Zuraimi et al. [128] observed the effects on health of different ventilation systems, noting more symptoms where there was hybrid ventilation, while the combination of air conditioning and mechanical ventilation seemed to have a negative effect on rhinitis compared with natural ventilation. However, concentrations of air pollutants were not systematically higher in the case of hybrid ventilation. This was true for biological pollutants, temperature, relative humidity and ozone. Another study [60] shows that electrostatic air cleaning technology reduced rates of absenteeism by 55% after two years. Fine particles were also reduced by 78% and by 45% (outdoors and indoors, respectively). It is not only children's health that is affected by ventilation. Shaughnessy et al. [86] showed an association, albeit modest ($p<0.1$), between ventilation rates and students' performance in standardised maths tests.

Heating may have an impact on pollutant concentrations and health. Nikolic et al. [80] observed more air pollutants in schools with coal-fired heating than in those with central heating. Respiratory symptoms were also more common in the first group of schools. Marks et al. [73] compared pollution levels and the health effects of gas heaters with or without flues. Pollutant concentrations were apparently higher in the case of gas heaters without flues. In addition, this type of heating has been associated with morning wheezing and with morning coughing, wheezing and the use of a bronchodilator in the atopic group. Lastly, building age is suspected to have an impact on occupants' health. Kim et al. [65] observed a tendency towards more symptoms in recently built schools compared to older buildings.

Other building-related characteristics that have been studied are the impact of renovation on health, and the effect of moisture damage. Renovation appears to be beneficial to children's health in most cases: it has a positive effect on stuffy nose, rhinitis, sore throat, hoarseness, coughing, eye symptoms and fatigue [72, 73]. Building moisture damage has a negative impact on health, with more frequent symptoms in damaged schools [107, 108]. In addition, there was greater mould proliferation in damaged schools than in reference schools [72]. In Koskinen et al. [69], in a day-care centre with mould problems the overall morbidity increased in comparison with the reference day-care centres. Children suffered from upper respiratory tract symptoms at least once during the study period (sore throat and nasal congestion). A significantly elevated risk of sore throat, hoarseness, nasal congestion, purulent and non-purulent nasal discharge, cough and common cold was found when the total numbers of symptom days were compared. Children exposed to mould had such symptoms repeatedly, or symptoms were prolonged. Lastly, in schools constructed from brick, a higher risk was found of nocturnal cough and cough without phlegm due to moisture damage, compared to schools made from wood [75].

Materials used inside for floors or walls also have an impact. Csobod et al. [20] found a link between plastic flooring and doctor-diagnosed allergies (OR 1.33). Norbäck et al. [82] found that wall-to-wall carpets in the workplace were related to chronic symptoms in teachers. Smedje et al. [104] also showed that shelves increased current asthma risk (OR 1.4, CI 95% 1.2–1.6). Activities inside buildings have an impact on occupants' health. Cleaning frequency and materials used can also affect children's and teachers' health [115].

4.9.5 Indoor air quality and attention/concentration tests

Table 40 presents the relationships between chemical, physical and comfort parameters and attention/concentration test results. Regression coefficients of the associations between the IAQ parameters and the attention test results were evaluated by linear regression without (b1) and with (b2) adjustments for age, gender, maternal education, environmental tobacco smoke and country. No significant association was found between the following chemical parameters (even after adjustment for the most important confounders) and the results of the attention/concentration test: benzo(α)pyrene, $PM_{2.5}$ and limonene.

Table 40. Relationships between chemical, physical and comfort parameters and attention/concentration test results

Classroom characteristics	Significant crude association with	Significant adjusted# association with
Formaldehyde	-	Inverse association with morning and afternoon mathematical test results
Benzene	-	Inverse association with morning and afternoon mathematical test results
α pinene	Inverse association with both morning and afternoon mathematical test results Inverse association with the difference between afternoon and morning logical test results	-
Ozone	Difference between afternoon and morning logical test results	-
T3CE	Inverse association with morning logical test results	-
Naphthalene	Inverse association with morning logical test results	-
CO_2	Inverse association with morning logical test results	Inverse association with morning logical test results
Ventilation rate	-	Positive association with afternoon logical test results

4.9.6 Classroom characteristics and attention/concentration test results

Regression coefficients of the associations between classroom characteristics and attention test results were evaluated by linear regression without (b1) and with (b2) adjustments for age, gender, maternal education, environmental tobacco smoke and country. The statistically significant associations are presented in Table 41. No significant association was found between the following classroom characteristics (even after adjustment for the most important confounders) and the results of the attention/concentration test: open windows during cleaning; furniture installed within one year; blackboard with chalk; whiteboard with alcohol-based markers; children using products with an irritant smell; classrooms with mouldy odour; classrooms with visible signs of moisture damage; and very dusty classrooms.

Table 41. Relationships between classroom characteristics and attention/concentration test results in SINPHONIE

Classroom characteristics	Significant crude association with	Significant adjusted# association with
Floor level	Mathematical and logical test results in the morning were better in classrooms situated on upper floors The difference between the results of the second and first logical tests was greater in classrooms on the ground floor	Mathematical results in the morning were better in classrooms on the ground floor
Occupation density ($<2m^2$/child)	Poor results in the logical test both in the morning and the afternoon in crowded classrooms	-
Orientation of classroom		
Street	-	-
Plastic floor	The difference between the results of the second and first mathematical tests was greater in classrooms with plastic flooring than in those with other floor material	-
Wall covering		
Water-resistant paints	Poor results in the logical tests both in the morning and, especially, in the afternoon	Poor results in the logical tests both in the morning and, especially, in the afternoon
Water-soluble paints	Better results in the logical tests both in the morning and in the afternoon	Better results in the logical tests both in the morning and in the afternoon
Wallpaper	Better results in the mathematical test in the morning	Better results in the mathematical test in the morning The difference between the results of the second and first logical tests was greater in classrooms with wall-paper than in classrooms with other wall coverings

Table 41. Relationships between classroom characteristics and attention/concentration test results (cont.)

Classroom characteristics	Significant crude association with	Significant adjusted# association with
Painted with water-soluble paints within the last 12 months	Poorer results in both the mathematical and logical tests in the afternoon The differences between the results of the second and first tests were greater in classrooms painted earlier	Poorer results in both the mathematical and logical tests in the afternoon than in the morning The differences between the results of the second and first tests were greater in classrooms painted earlier
Painted with whitewash during the last 12 months	Better results in both the mathematical and logical tests in the afternoon than in the morning	
Ventilation		
Air conditioning	Better results in the mathematical tests in the morning; in the afternoon the results were very poor	Better results in the mathematical tests in the morning; in the afternoon the results were very poor
Mechanical ventilation	Associated with good logical test results both in the morning and in the afternoon	Associated with poor logical test results both in the morning and in the afternoon
Windows opened two or three times/day or less	Poor results in the logical test, especially in the afternoon The differences between the results of the second and first tests were greater than in classrooms with other ventilation regimes	Poor results in the logical test, especially in the afternoon The differences between the results of the second and first tests were greater than in classrooms with other ventilation regimes
Cleaning schedule		
Cleaning once a day or less frequently	-	Poor results in the logical and mathematical tests in the afternoon in less frequently cleaned classrooms
In the morning before school time	Poorer results in both the logical and mathematical tests in the afternoon than in the morning	The differences were greater

Table 41. Relationship between classroom characteristics and attention/concentration test results (cont.)

Classroom characteristics	Significant crude association with	Significant adjusted# association with
In the evening after school time	Poor results in the mathematical test both in the morning and in the afternoon Better results in the logical test in the afternoon The positive difference between the afternoon and the morning logical test results was greater than in other classrooms	Poor results in the mathematical test both in the morning and in the afternoon
Means of classroom cleaning		
Vacuum cleaner	Better results in the logical tests in the afternoon	The differences between the results of the second and first tests were greater than in classrooms cleaned by other means
Broom	-	Better results in the logical test in the morning
Mop	Poor results in the logical test in the afternoon	Poor results in the logical test in the afternoon
Mop with bleach	Poor results in both the mathematical and logical tests in the morning	Poor results in both the mathematical and logical tests in the morning

4.9.7 Classroom characteristics and absenteeism

Regression coefficients of the associations between classroom characteristics and absenteeism were evaluated by linear regression without (b1) and with (b2) adjustments per SINPHONIE country. The statistically significant associations are presented in Table 42.

No significant association was found between the following classroom characteristics (even after adjustment for country) and absenteeism: floor level; occupation density (<2 m^2/child); classroom orientation (street); plastic floor; ventilation; windows opened two or three times/day or less; cleaning schedule (once a day or less frequently; in the evening after school); open windows during cleaning; furniture installed within one year; blackboard with chalk; whiteboard with alcohol-based markers; children using products with an irritant smell; mouldy odour; visible signs of moisture damage; and very dusty classroom.

There was no reasonable significant association observed between measured concentrations and absenteeism.

Table 42. Relationships between classroom characteristics and absenteeism

Classroom characteristics	Significant crude association with	Significant adjusted# association with
Wall covering		
Wallpaper	Associated with higher absenteeism than in classrooms with some other covering (13.6% vs. 5.4% mean absenteeism per day; and for days with any absenteeism 84.9% vs. 50.4%)	Associated with higher absenteeism than in classrooms with some other covering (13.6% vs. 5.4% mean absenteeism per day; and days with any absenteeism 84.9% vs. 50.4%)
Cleaning schedule		
In the morning before school	-	Significantly higher average absenteeism in classrooms cleaned in the morning
Means of classroom cleaning		
Vacuum cleaner	Highly associated with absenteeism	

4.10 Health outcomes and exposure to outdoor air pollution

In the ad hoc assessment performed within SINPHONIE, no significant relationships were found between exposure to outdoor air pollution and health outcomes, except among kindergarten children who suffered from at least one symptom significantly related to elevated exposure to NO_2 (Table 43). A slight trend was observed for formaldehyde in schoolchildren.

Table 43. Relationships between outdoor chemical air pollutants and having suffered from at least one recent (<3 months) symptom in children, and having suffered from a symptom in teachers

	Schoolchildren	Kindergarten children	Teachers
Formaldehyde	1.17 [0.90-1.52]* *p*=0.20	-	-
Benzene			
Naphtalene	-	-	-
Limonene	-	-	-
T3CE	-	-	-
T4CE	-	-	-
NO_2	-	-	-
$PM_{2.5}$	-	2.00 [1.06, 3.79] *p*=0.03	-
Ozone	-	-	-

*Odds ratio [95% confidence interval] adjusted for age, gender, smoking, domestic pets, house near traffic area, zone and school

4.11 Absenteeism and asthma management in school

Among chronic diseases, asthma is one of the most common causes of absenteeism from school. In addition, many children are likely to be affected by, or encounter, asthma attacks at school. In the SINPHONIE study, asthma was responsible for significant levels of absenteeism among schoolchildren (Figures 62 and 63).

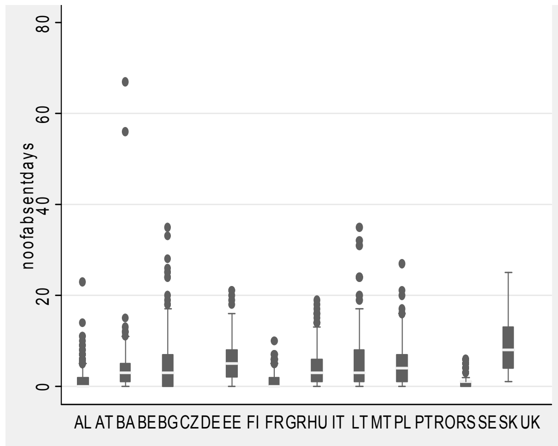


Figure 62. Total number of days absence from school among schoolchildren

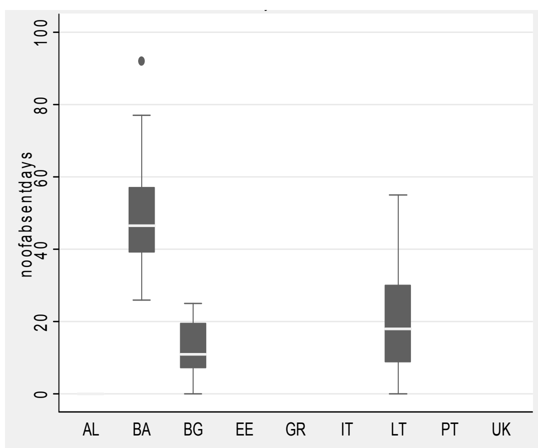


Figure 63. Total number of days absence among kindergarten children

The number of days of absence statistically increased in the case of elevated levels of naphthalene, limonene and CO_2, and was inversely related to T3CE, T4CE and various bio-contaminants (PenAsp, Cherb, Aaltr, Myvo cells). Among the covariates adjusted for, the total number of days of absence was associated (or showed a trend) with stress at school, low level of maternal education, house near traffic, exposure to smoking and body mass index. Low household income, gender and domestic pets were not associated with the total number of days absent in the model fully adjusted for other covariates.

Variations in the number of days of absence were also found among kindergarten children, where the risk of absenteeism strongly increased with elevated levels of limonene, NO_2, $PM_{2.5}$, ozone, T3CE and T4CE in the classroom. However, absenteeism was inversely related to Avers and Myco cells and to cat allergen. Ventilation was inversely related to absenteeism in young children.

In the SINPHONIE study, 65 children were allowed to bring their asthma medication to school. Sixty children (1.1%) suffered from an asthma attack at school, with 42 of them managing their asthma themselves. The asthma attacks occurred mostly in classrooms (N=26) and during sports practice (N=23). Nineteen children needed to attend an emergency department. Boys were at higher risk than girls of suffering from an asthma attack at school.

Offering an interactive, integrated health-awareness curriculum (including asthma management) in elementary classrooms could provide an opportunity to increase knowledge and develop health literacy about a leading chronic disease among school-aged children while enhancing core content areas. The development of such a curriculum would expand the availability of resources for teachers wanting to use an integrated approach to introducing real-world topics in their classrooms. Future work is needed to enhance the potential for dissemination, including the development of integrated curricula that can address other health topics as well.

4.12 Methodological issues

The SINPHONIE results must be interpreted with caution. It would not be possible for a multidisciplinary study such as SINPHONIE to establish whether air quality in primary schools and kindergartens is responsible for observed symptoms and diseases among children and teachers. However, the fact that excess risk of symptoms and diseases was found in primary schools and kindergartens with poor air quality, after having adjusted for potential confounders, supports the hypothesis that such a link exists. In addition, the fact that a significant relationship was found overall with recent symptoms and diseases supports the hypothesis of the influence of the school/kindergarten environment.

The SINPHONIE results were adjusted for several confounders. In other words, adjustments were made for factors capable of contributing to impaired health, such as passive smoking, family history of allergy and asthma, and socioeconomic factors, in order to better investigate the role of air quality in schools and kindergartens.

Another reason for caution is the fact that the air quality assessed within SINPHONIE may not have been representative of typical air quality patterns occurring in a given school environment, and, as a result, environmental exposures may have been misclassified. This is particularly true for outdoor air pollution. Similarly, there may have been health misclassification through the use of questionnaires. The interrelationships among chemical air pollutants, bio-contaminants and attention tests also need to be further explained, which could result in some modifications. These could explain, for example, why inverse relationships were found among certain air pollutants and health outcomes. A final critical issue is the representativeness of the population and the reduced sample size overall in the case of clinical assessments. In SINPHONIE, small samples were targeted and these were much reduced in the case of kindergarten children and teachers.

5 Health Risk Assessment of Indoor Air Quality in Schools

5.1 Main indicators: overall and cluster-based assessment

The process of risk assessment in the case of human health effects involves the following steps (European Commission Directive 93/67/EEC 1993):

1. *Hazard identification*: the identification of the adverse effects that a given substance has an inherent capacity to cause.
2. *Dose-response assessment*: the estimation of the relationship between the dose or level of exposure to a substance, and the incidence and severity of an effect.
3. *Exposure assessment*: the determination of the emissions, pathways and transformations in order to estimate the concentrations/doses to which human populations are or may be exposed.
4. *Risk characterisation*: the estimation of the incidence and severity of the adverse effects likely to occur in a human population or environmental compartment due to actual or predicted exposure to a substance, which may include risk estimation — that is, the quantification of that likelihood.

A review of the literature on the health effects of exposure to indoor air pollutants in schools was carried out in order to: a) define the list of key indoor air pollutants affecting IAQ in schools; and b) collect toxicological data for the health risk assessment (see annex 2). The main sources of information included were health-based guidelines, such as the WHO air quality guidelines, for both outdoor and indoor air, and the report of the EU-INDEX project 'Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU' [70].

The following were evaluated:

- The WHO Air Quality Guidelines for Europe, second edition (2000) [119], which contain health risk assessments of 28 chemical air contaminants.
- The WHO Air Quality Guidelines "Global Update" (2005), which focuses on a small group of pollutants (PM, ozone, NO_2 and SO_2) but also includes chapters addressing some general, health-related subjects of importance to the air pollution field, including a chapter on IAQ [120].
- The WHO Guidelines for Indoor Air Quality: Selected Pollutants, published in 2010 [125], which recommends targets defined to protect public health in relation to nine air pollutants commonly present in the indoor air and provides a scientific basis for legally enforceable standards in the countries of the WHO region.
- The EU-INDEX project [70], which was funded by the European Commission's DG SANCO and coordinated by the Joint Research Centre (JRC). The list of selected compounds contains nine chemicals that may potentially be present in high concentrations in indoor environments, have uncontested health impacts, and require effective risk management to regulate them with priority. For each selected compound, guideline values and risk management options are recommended.

- The WHO Guidelines on Dampness and Mould, published in 2009 [124], which conclude that persistent dampness and microbial growth on interior surfaces and in building structures should be avoided or minimised, as it may lead to adverse health effects. As the relationships between dampness, microbial exposure and health effects cannot be quantified precisely, no quantitative, health-based guideline values or thresholds can be recommended for acceptable levels of contamination by microorganisms. The available studies do not provide information about health risk assessment in relation to levels of contamination by microorganisms.

5.1.1 Chemical parameters

Particulate matter

Airborne PM is a composite of hundreds of different substances that exist as particles that are extraordinarily heterogeneous in terms of chemical property and size, with a high degree of spatial and temporal variability.

Levels of indoor PM concentrations depend on outdoor and indoor sources of PM. Outdoor combustion particles arise from industrial smokestack emissions, vehicle exhausts (diesel/gasoline), heating exhausts (from coal or wood), forest fires, and other open fires or incineration (e.g. yard waste and trash burning). The extent to which these particles from outdoor sources affect a building's indoor air depends on the building's location, how close it is to the outdoor source, the type of ventilation system in use, the proportion of outdoor and indoor air mixture, and the location of the air intakes. Indoor combustion particulate sources include heating appliances, dry-process photocopying machines, cooking appliances and tobacco smoke.

Epidemiological studies suggest that PM air pollution, at levels common to many urban and industrial areas, contributes to human morbidity and mortality in terms of cardiorespiratory diseases. The principal health effects associated with PM exposure include premature mortality, the aggravation of respiratory and cardiovascular diseases, changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defence mechanisms. Decreased lung function and increased respiratory symptoms are associated with increased PM concentrations in epidemiological studies and controlled laboratory exposure studies of laboratory animals and humans. The observation of these PM-associated effects in children is particularly worthy of note.

Epidemiological data indicate that several sub-populations are at increased risk of PM exposure, particularly children, individuals with respiratory diseases (e.g. chronic obstructive pulmonary disease, acute bronchitis, asthma, pneumonia) and cardiovascular disease (e.g. pneumonia), and the elderly.

The WHO 2005 guideline values [123] for $PM_{2.5}$ are 25 $\mu g/m^3$ (24-hour mean) and 10 $\mu g/m^3$ (annual mean), which are considered sufficient to protect from long-term effects on cardio-vascular-respiratory function and lung cancer mortality. The steering group assisting WHO in designing the IAQ guidelines concluded that there is no convincing evidence of a difference in the hazardous nature of PM from indoor sources as compared with PM from outdoor sources, and that the indoor levels of PM_{10} and $PM_{2.5}$, in the presence of indoor sources of PM, are usually higher than the outdoor PM levels. Therefore, the air quality guidelines for PM recommended by the 2005 Global Update are also applicable to indoor spaces and a new review of the evidence was not considered necessary.

The results of indoor $PM_{2.5}$ measurements in schools in the framework of the SINPHONIE project show values ranging from 3.6 to 250 $\mu g/m^3$, with significant differences among the participating countries. The $PM_{2.5}$ indoor levels in schools in SINPHONIE Cluster 4 (Southern Europe) and Cluster 3 (Central-Eastern Europe) were significantly higher than in Cluster 1 (Northern Europe) and Cluster 2 (Western Europe).

The indoor/outdoor ratio was 1.4 in the heating season and 1.9 in the non-heating season, indicating the presence of indoor sources of $PM_{2.5}$ in addition to the outdoor air (traffic). The re-suspension of PM due to classroom occupation, activities and movements is probably the main contributor to the indoor sources of $PM_{2.5}$.

Overall, only 40% of children were exposed to $PM_{2.5}$ less than 10 $\mu g/m^3$; 47% to between 10 and 25 $\mu g/m^3$; and 13% to more than 25 $\mu g/m^3$, thus presents a risk of long-term effects on cardio-vascular-respiratory function and lung cancer mortality.

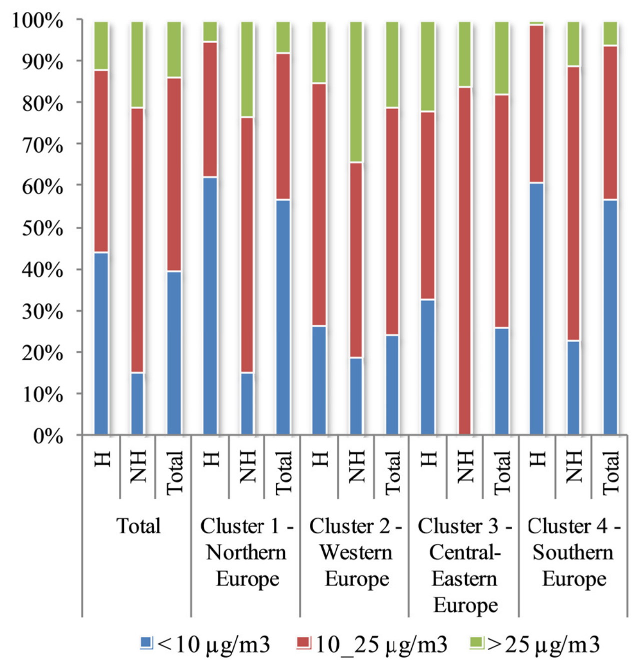


Figure 64. $PM_{2.5}$ exposure distribution among schoolchildren for the total population and for the four SINPHONIE geographical clusters for heating (H) and non heating (NH) season

Figure 64 shows the $PM_{2.5}$ exposure distribution among schoolchildren for the total population and for the four SINPHONIE geographical clusters in relation to the WHO guideline values. For each cluster, the exposure in the heating and non-heating season and the total exposure (heating and non-heating) are shown. However, due to the low number of pupils assessed in the non-heating season the values should be interpreted with caution. Considering the total values (for both the heating and non-heating seasons) in SINPHONIE Cluster 2 (Western Europe) and in Cluster 3 (Central-Eastern Europe), a higher percentage of children were exposed to $PM_{2.5}$ in schools at concentration levels higher than 10 μg/m^3.

Benzene

Indoor benzene may originate from the outdoor air or from indoor sources such as building materials, vinyl, rubber and PVC floorings, as well as nylon carpets, furniture and heating. Outdoor benzene concentrations are mainly due to traffic.

The major health risk associated with low-level exposure to benzene is leukaemia, and the strongest link in humans is with acute non-lymphocytic leukaemia (ANLL). The lowest level of exposure at which an increased incidence of ANLL among occupationally exposed workers has been reliably detected appears to be in the range of 32 to 80 mg/m^3. There is no evidence that continuous exposure to environmental levels of benzene manifests as any other adverse health effect.

Benzene is classified by the International Agency for Research on Cancer (IARC) [46] as a known human carcinogen. No safe level of exposure to benzene can be recommended; therefore its indoor air concentration should be kept as low as reasonably achievable and should not exceed its outdoor concentration levels. Recommended management options are to ban benzene sources indoors, and to lower the permissible benzene content in any building material and consumer product.

The estimated unit risk of leukaemia per 1 μg/m^3 is 6×10^{-6}, and the excess lifetime risk of 1/10,000, 1/100,000 and 1/1000,000 is 17, 1.7 and 0.17 μg/m^3 respectively.

In the Air Quality Directive (2008/EC/50) [26], the EU set a limit value for benzene defining the annual mean value of benzene may not exceed 5 μg/m^3. This limit value is in effect for data measured after January 1, 2010; however, it has not to be considered as a safe level of exposure of benzene.

The results of indoor benzene measurements in schools in the framework of the SINPHONIE project show values ranging from 0 to 38 μg/m^3, with large differences among the participating countries. Indoor benzene levels in schools in SINPHONIE Cluster 1 (Northern Europe) and Cluster 2 (Western Europe) are significantly lower than in Cluster 3 (Central-Eastern Europe) and Cluster 4 (Southern Europe), which suggests that indoor benzene concentrations increase from north to south.

The indoor/outdoor ratio of benzene concentrations was 1.5 in the heating season and 3.4 in the non-heating season, suggesting that there are indoor sources of benzene in the schools in addition to traffic and industrial sources, for example tobacco smoke, cleaning products, furniture, wall coverings (paints), and floor coverings (wooden flooring, linoleum, PVC flooring).

The benzene exposure distribution among schoolchildren for the total population and the benzene exposure distribution among schoolchildren for the total population and for the four

European clusters are presented in relation to the EU limits in Table 44 and Figure 65 respectively. Around 25% of children were exposed to benzene in schools at concentration levels greater than 5 μg/m^3, with higher percentages in SINPHONIE Cluster 3 (Central-Eastern Europe).

Table 44. Benzene exposure distribution among SINPHONIE schoolchildren

Min., percentiles, max.	Benzene (μg/m^3)
Minimum	< Detection limit
10th percentile	0.5
25th percentile	1.0
50th percentile	2.2
75th percentile	4.7
90th percentile	11.1
Maximum	38

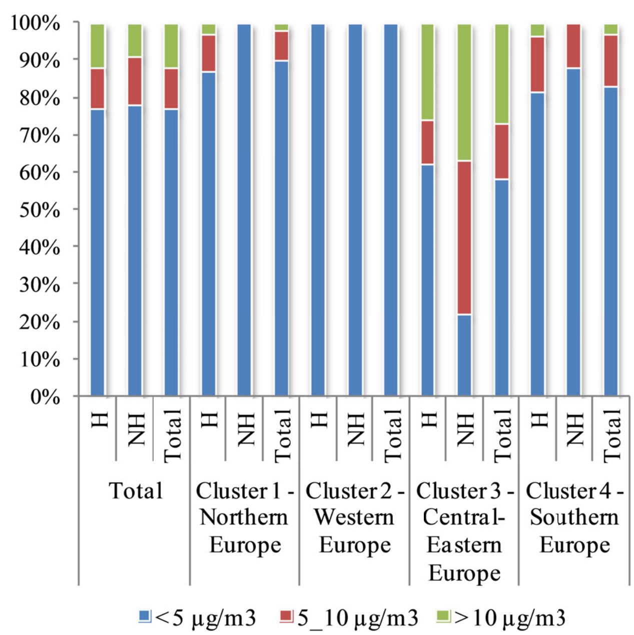


Figure 65. Benzene exposure distribution among SINPHONIE schoolchildren for the total population and for the four SINPHONIE geographical clusters for heating (H) and non heating (NH) season

The significantly higher benzene exposure level in schools in Eastern European countries suggests a higher excess lifetime risk of leukaemia. Based on the estimated unit risk of leukaemia (6×10^{-6}) exposure to 5 and 10 μg/m^3 are related to an excess lifetime risk of 3/100,000 and 6/100,000. Based on unit risk estimations of the WHO guidelines, the benzene median exposure level is linked to a risk level of 1.3×10^{-5}, and an excess lifetime leukaemia risk of 1:76,923 in the total population studied, and a risk level of 2.0 x 10^{-5} corresponding to an excess lifetime leukaemia risk of 1:50,000 in schoolchildren from Central-Eastern European countries.

Formaldehyde

The main indoor sources of formaldehyde include urea-formaldehyde resins that are used widely as glues in the manufacturing of wooden products such as particleboard and plywood. Formaldehyde may also be used in urea-formaldehyde foam insulation. Formaldehyde can be released over long periods of time, even years, at a slowly decreasing rate. Indoor concentrations are influenced by temperature, relative humidity, ventilation rate, age of the building, product usage, the presence of combustion sources, and the smoking habits of the building's occupants. It may also be formed in the indoor air due to ozone-initiated chemical reactions and transformations in the presence of abundant concentrations of terpenes, which may occur due to the use of some consumer products such as fragrances and air fresheners.

Formaldehyde has a pungent odour and has irritating properties that cause discomfort. The symptoms displayed after short-term exposure to formaldehyde are: irritation of the eyes, nose and throat, together with exposure-dependent discomfort, lachrymation, sneezing, coughing, nausea and dyspnoea. Children have been reported to be more sensitive when exposed to formaldehyde. Formaldehyde is classified by the IARC as carcinogenic for humans (Group 1: nasopharyngeal cancer in humans at high levels). The harmonised classification and labelling system of the European Chemicals Agency recently classified formaldehyde as a category 1B carcinogen (A substance belonging to Category 1 is known or presumed to have carcinogenic/mutagenic potential for humans. For Category 1A the assessment is based primarily on human evidence, whereas for Category 1B the assessment is based primarily on animal evidence).

Management options are to restrict and avoid the use of formaldehyde-containing materials and products in buildings.

A 30-minute guideline of 0.1 mg/m^3 is recommended by the WHO 2010 guidelines to prevent sensory irritation due to formaldehyde in the general population. This guideline value, valid for any 30-minute exposure period, also prevents the effects of long-term exposure on lung function or the risk of nasopharyngeal cancer. It should be underlined that these concentration levels cannot be directly compared with the values measured in the SINPHONIE project, as these latter are only related to a week-long period of sampling.

In 2007, the French Environmental Agency (AFSSET) [1] proposed a long-term formaldehyde guideline value for the indoor environment of 50 μg/m^3 (for two-hour exposure) and 10 μg/m^3 (for long-term exposure) to protect from acute sensory irritation, long-term effects on lung function and cases of formaldehyde-induced nasopharyngeal cancer. These guideline values for formaldehyde were used to tentatively evaluate the SINPHONIE results as they better match the week-long SINPHONIE measurements and are therefore a better basis for comparison than the relevant WHO guideline values.

The results of indoor formaldehyde measurements in schools in the framework of the SINPHONIE project show values ranging from 1.3 to 66.2 μg/m^3, with large differences between participating countries. The indoor formaldehyde concentration levels in schools were significantly higher in SINPHONIE Cluster 2 (Western Europe) and Cluster 3 (Central-Eastern Europe) than in Cluster 1 (Northern Europe) and Cluster 4 (Southern Europe).

As might be expected, the indoor/outdoor concentration ratio was 7 in the heating season and 8.9 in the non-heating season, and this confirms that indoor sources are the dominant contributor of exposure to formaldehyde. The higher concentration of formaldehyde during the summer season may be due to the higher emission rate of formaldehyde from its indoor sources at relatively higher temperatures and relative humidity.

Table 45. Formaldehyde exposure distribution among SINPHONIE schoolchildren

Min., percentiles, max.	Formaldehyde (μg/m^3)
Minimum	1.3
10th percentile	6.3
25th percentile	8.1
50th percentile	12
75th percentile	18.9
90th percentile	30
Maximum	66.2

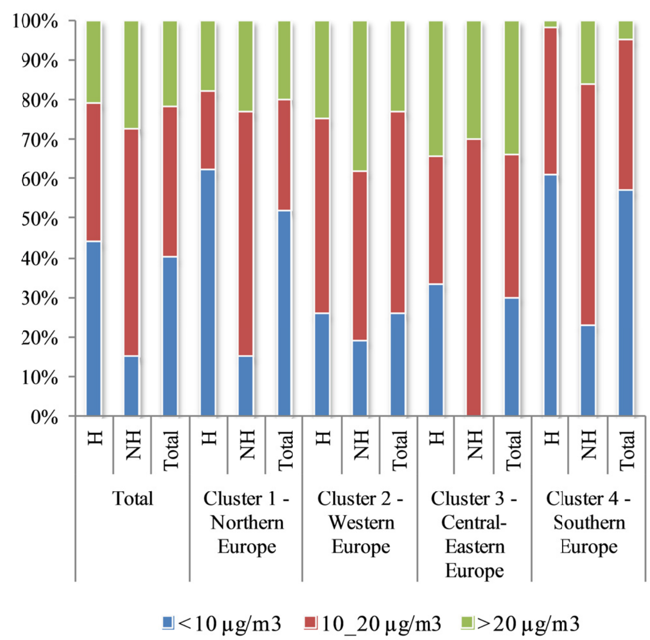


Figure 66. Formaldehyde exposure distribution among SINPHONIE schoolchildren for the total population and for the four SINPHONIE geographical clusters in relation to the AFSSET guideline values for heating (H) and non heating (NH) season

Error! Reference source not found. 45 shows that 50% of children were exposed to formaldehyde in schools at concentration levels of 12 µg/m^3. A total of 60% of children were exposed to formaldehyde in school at more than 10 µg/m^3, which is the guideline value proposed by *AFSSET* as a long-term formaldehyde guideline value for indoor environments; 38% to between 10 and 20 µg/m^3; and 22% to more than 20 µg/m^3. Fewer than 5% of schoolchildren were exposed to more than 50 µg/m^3, proposed by *AFSSET* as a short-term (two-hour) formaldehyde guideline value for indoor environments.

Figure 66 shows the formaldehyde exposure distribution among SINPHONIE schoolchildren for the total population and for the four SINPHONIE geographical clusters in relation to the AFSSET guideline values.

Radon

Radon gas is an important source of ionizing radiation of natural origin and a major contributor to the ionizing radiation dose received by the general population. The main source of indoor radon is the radon produced by the decay of radium in the soil subjacent to a building. The most important route of exposure to radon and its decay products is inhalation. Radon is connected to lung cancer (being principally responsible among all causes of cancer in humans).

Radon is a known human carcinogen with genotoxic action (IARC Group I). The excess lifetime risk of death from radon-induced lung cancer is 6 x 10^{-4} per Bq/m^3. In view of the latest scientific data on the health effects of indoor radon, in 2010 WHO recommended a national residential reference level below 100 Bq/m^3. Where it is not possible to achieve this level, the chosen reference level should not be higher than 300 Bq/m^3.

The results of indoor radon measurements in schools in the framework of the SINPHONIE project show values ranging from 0 to 9,186 Bq/m^3 (median value 100.9 Bq/m^3), with significantly higher levels in SINPHONIE Cluster 3 (Central-Eastern Europe) and Cluster 4 (Southern Europe) than in Cluster 1 (Northern Europe) and Cluster 2 (Western Europe) (Figure 67). Half the children were exposed to more than 100 Bq/m^3 of radon (the national residential reference value proposed by WHO in 2010) leading to higher lung cancer risk. High radon concentration values were detected only in one Portuguese school, where 66 of pupils were exposed to extremely high levels of radon, comparable only to professional exposure. In terms of risk management, as soon as the problem was detected and confirmed by a second analysis and on-site monitoring, the school was closed and the children relocated to another school building.

As expected, the indoor/outdoor concentration ratio for radon in the SINPHONIE schools was 6.4 in the heating season and 2.3 in the non-heating season. This confirms that indoor levels of radon are higher than outdoor levels and also shows the beneficial effect of increasing ventilation during the non-heating season.

A regional assessment of the results shows that SINPHONIE Cluster 4 (Southern Europe) and Cluster 3 (Central-Eastern Europe) have significantly higher indoor radon concentrations than the other two SINPHONIE clusters. Based on mean levels, the lowest risk level of

3 x 10^{-2} was shown in SINPHONIE Cluster 1 (Northern Europe), while the highest was in Cluster 3 (Central-Eastern Europe), corresponding to a risk level of 9.6 x 10^{-2}.

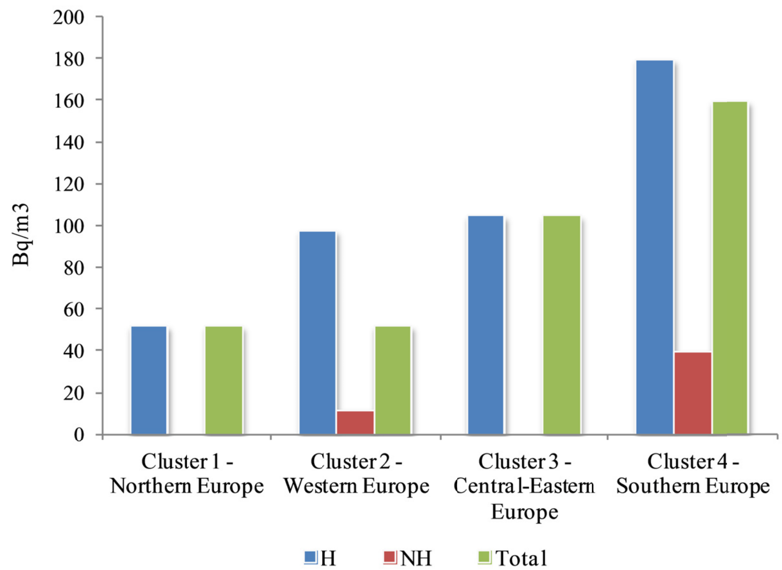


Figure 67. Indoor radon levels in schools in the four SINPHONIE geographical clusters in the heating (H) and non-heating (NH) seasons

Carbon monoxide

Carbon monoxide is a colourless, odourless and tasteless gas. It is a product of the incomplete combustion of carbon-containing materials, but is also produced by some industrial and biological processes. Carbon monoxide is widely generated indoors by unvented combustion appliances, particularly if they are operated in poorly ventilated rooms. Tobacco smoke is also an important source of indoor CO pollution.

Accidental exposure to high levels of CO is a frequent cause of death. At lower levels, exposure leads to reduced exercise ability and increased risk of ischemic heart disease. Epidemiological studies involving large population groups, where CO exposures were generally at relatively low levels, have demonstrated increased incidences of low birth weight, congenital defects, infant and adult mortality, cardiovascular admissions, congestive heart failure, strokes, asthma, tuberculosis and pneumonia. A series of guidelines is recommended to prevent the effects of short peaks of CO exposure. In 2010, WHO proposed a guideline value of 7 mg/m^3 (corresponding to 6 ppm) (as a 24-hour mean CO concentration) to prevent the effects of chronic exposure to CO.

With the exception of one classroom, where very elevated indoor levels of CO were observed (121.8 ppm), all the SINPHONIE schoolchildren were exposed to less than the 6 ppm WHO guideline value (50^{th} percentile, 0.2 ppm; 90^{th} percentile, 1.3 ppm).

Nitrogen dioxide

Nitrogen dioxide is a gas with a pungent, acrid odour. Generally, NO_2 is emitted from indoor combustion sources. Indoor NO_2 levels are mainly influenced by outdoor sources, however in some cases indoor sources may be also relevant. The outdoor sources are related to traffic or some other combustion sources. NO_2 levels in school classrooms are significantly correlated with distance from roads with heavy traffic [77]. These comprise tobacco smoke, gas appliances, kerosene heaters, woodstoves and fireplaces. Additionally, the outdoor air can act as a source of indoor NO_2 pollution. The most elevated outdoor concentrations of NO_2 are generally found in cities and near busy roads. Nitrogen dioxide is an oxidising agent that is highly irritating to the mucous membranes and causes a wide variety of health effects. Most studies demonstrate substantial changes in pulmonary function in normal healthy adults at NO_2 concentrations above 2 ppm. Asthmatics appear to be responsive at about 0.5 ppm, and subjective complaints have been reported at that level. Nitrogen dioxide increases bronchial reactivity as measured by pharmacological bronchoconstriction agents in normal and asthmatic subjects, even at levels that do not affect pulmonary function directly in the absence of a bronchoconstriction agent. Epidemiological studies suggest that children who are exposed to combustion contaminants from gas stoves have higher rates of respiratory symptoms and illness than other children. There have been concerns that infants may be at a higher risk of symptoms from exposure to high indoor NO_2 levels because of their high respiratory minute volume in relation to body size and because they are likely to spend a large proportion of their time indoors.

An indoor NO_2 guideline of 40 $\mu g/m^3$ (annual mean) was recommended by WHO in 2010 [125] and by the EU-INDEX project in 2005 (weekly mean) [70]. In the Air Quality Directive (2008/EC/50) [26], the EU set a similar limit value (40 $\mu g/m^3$ as annual mean). This guideline value is intended to reduce the risk of a broad range of respiratory symptoms associated with NO_2 exposure.

The results of indoor NO_2 measurements in schools in the framework of the SINPHONIE project show values ranging from 0.1 to 87.8 $\mu g/m^3$. Levels of indoor NO_2 in schools were significantly higher in SINPHONIE Cluster 2 (Western Europe) and Cluster 4 (Southern Europe) than in Cluster 1 (Northern Europe) and Cluster 3 (Central-Eastern Europe). The indoor/outdoor concentration ratio for NO_2 was 0.8 in the heating season and 0.9 in the non-heating season.

With the exception of seven classrooms (2% of all monitored classrooms) where elevated NO_2 indoor levels were observed, all schoolchildren were exposed at levels lower than the WHO guideline value of 40 $\mu g/m^3$ (50^{th} percentile, 11.4 $\mu g/m^3$; 90^{th} percentile, 26.4 $\mu g/m^3$).

Ozone

Ozone is a gas that is naturally created in outdoor photo-oxidation reactions by sunlight, and artificially created as a by-product of human activities both outdoors and indoors. Outdoors, particularly in urban settings near areas with dense traffic, levels of ozone can become sufficiently elevated to cause health problems, especially in sensitive individuals such as elderly persons or asthmatics. Since outdoor air is drawn into buildings through ventilation systems or open windows, elevated outdoor ozone levels can cause elevated levels indoors. A number of indoor sources can further increase ozone levels. The major indoor source of ozone is office equipment, such as computer terminals, laser printers and photocopiers. High densities of such equipment and/or deficiencies in ventilation systems in buildings can lead to elevated ozone levels that may cause adverse health effects.

Ozone, being a strong oxidant, can have various physiological effects on pulmonary (lung) function, including decreases in lung function, air exchange rates and airway permeability. Ozone can also act as an irritant. The health impacts of exposure to elevated ozone levels include eye irritation, shortness of breath (dyspnoea), coughing, asthma, excessive mucous production, mucous membrane irritation, and chest pain upon inspiration. Subjects such as asthmatics and those with allergic rhinitis may be particularly susceptible to the effects of elevated ozone.

An ozone air quality guideline of 100 $\mu g/m^3$ (eight-hour mean) was recommended by WHO in 2005, and 120 $\mu g/m^3$ by EU Air Quality Standards for ambient air quality. This guideline value is intended to reduce the risk of a broad range of respiratory symptoms associated with ozone exposure.

The results of indoor ozone measurements in schools in the framework of the SINPHONIE project show values ranging from 0 to 141 $\mu g/m^3$. Indoor levels of ozone in schools were significantly higher in SINPHONIE Cluster 4 (Southern Europe) and Cluster 3 (Central-Eastern Europe) than in Cluster 1 (Northern Europe) and Cluster 2 (Western Europe).

With the exception of one classroom, where elevated ozone indoor levels were observed, all schoolchildren were exposed to levels lower than the WHO guideline value of 100 $\mu g/m^3$ (50^{th} percentile, 3.2 $\mu g/m^3$; 90^{th} percentile, 16 $\mu g/m^3$).

Volatile organic compounds

Volatile organic compounds are ubiquitous in the indoor environment, and the number of VOCs detected in the indoor air is usually higher than in the outdoor air and has been continuously increasing over the past decade. Various materials commonly found in school buildings emit many VOCs. Indoor concentrations may fluctuate widely with temperature, relative humidity, occupants' activities and ventilation patterns. Interior treatments, paints, polyurethane, coatings, sealants, polishes, cleaners and furnishings used in schools can emit numerous VOCs, particularly formaldehyde. The irritating emissions from pressed-wood products come mainly from the resins, adhesives and glues. Dry-cleaned fabrics can emit harmful concentrations of T4CE (also known as perchloroethylene or PERC).

Exposure to VOCs can result in both acute and chronic health effects. Volatile organic compounds can cause irritation of the eyes and respiratory tract and sensitisation reactions that involve the eyes, skin and respiratory tract. Symptoms of VOC exposure can include fatigue, headaches, drowsiness, dizziness, weakness, blurred vision, skin irritation, and irritation of the eyes and respiratory tract. There is some evidence that VOCs can provoke some of the symptoms typical of the so-called "sick building syndrome". Some VOCs are known human carcinogens (benzene) or animal carcinogens (carbon tetrachloride, chloroform, T3CE, T4CE, and p-dichlorobenzene). Volatile organic compounds such as 1,1,1-trichloroethane, styrene and pinene are mutagens and possible carcinogens.

Trichloroethylene

Trichloroethylene is a solvent commonly used in adhesives, paints, paint removers, varnishes, glues, rug-cleaning fluids, etc. Exposure to T3CE increases the risk of liver, kidney and testicular cancer as well as non-Hodgkin's lymphoma and leads to the recommendation of a non-threshold approach. Based on the WHO guidelines for IAQ [125], the estimated unit risk is 4.3×10^{-7} per $\mu g/m^3$ and the concentrations of airborne T3CE associated with an excess lifetime cancer risk of 1:10,000, 1:100,000 and 1:1000,000 are 230, 23 and 2.3 $\mu g/m^3$, respectively.

The results of indoor T3CE measurements in schools in the framework of the SINPHONIE project show a large range of concentration values (between 0 and 126 $\mu g/m^3$), with significantly lower indoor T3CE levels in SINPHONIE Cluster 2 (Western Europe) and Cluster 1 (Northern Europe) than in Cluster 4 (Southern Europe) and Cluster 3 (Central-Eastern Europe).

<u>10% of children were exposed to T3CE in schools at more than 5 $\mu g/m^3$ (50^{th} percentile < detection limit; 90^{th} percentile, 4.9 $\mu g/m^3$)</u>.

The significantly higher T3CE levels in Eastern and Southern countries suggest a higher lifetime risk of cancer, based on the unit risk estimations of the WHO guidelines. The highest T3CE mean levels are linked to a risk level of 1.5×10^{-5}, and an excess lifetime cancer risk of 1: 666,000.

Tetrachloroethylene

Tetrachloroethylene is a solvent that is typically used in dry-cleaning. Consumer products that may also contain T4CE include adhesives, fragrances, spot removers, stain removers, fabric finishes and wood cleaners. In 2010, WHO recommended a T4CE guideline value for year-long exposure of 250 $\mu g/m^3$ [125]. At higher exposures, effects can appear in the kidney, indicative of early renal disease, and impaired neuro-behavioural performance.

<u>None of the children were exposed to T4CE at levels higher than the recommended WHO guideline value, while 10% of children were exposed to T4CE in schools at more than 3.3 $\mu g/m^3$ (50^{th} percentile < detection limit; 90^{th} percentile, 3.3 $\mu g/m^3$)</u>.

Naphthalene

Indoor naphthalene originates from the outdoor air (motor vehicle exhausts) or indoor sources such as smoking, hair sprays, rubber materials and repellents (moth repellents in clothes cupboards and mosquito coils). The main health concerns related to exposure to naphthalene are respiratory tract lesions, including tumours in the upper respiratory tract. Based on the IARC classification, naphthalene is possibly carcinogenic to humans (Group 2B). A guideline value of 10 μg/m^3 was established by WHO in 2010 as an annual mean to prevent these risks [125].

Indoor concentrations of naphthalene in schools in the framework of the SINPHONIE project show values ranging from 0 to 30.8 μg/m^3. SINPHONIE Cluster 3 (Central-Eastern Europe) and Cluster 4 (Southern Europe) have significantly higher indoor naphthalene concentrations, although all mean values for all four SINPHONIE clusters are far below the WHO guideline value.

About 5% of children (corresponding to 12 classrooms) were exposed to naphthalene levels higher than the WHO recommended guideline value (for year-long exposure). Most of the children were exposed to very low levels of naphthalene (less than 1 μg/m^3) (50th percentile < detection limit; 90th percentile, 7.4 μg/m^3).

Limonene

Potential hazards of limonene exposure are eye and airway irritation. It has been proposed that reactions between unsaturated volatile compounds (e.g. limonene, α-pinene, styrene) and ozone or hydroxyl (OH) radicals produce chemically reactive products more likely to be responsible for eye and airway irritation than the chemically non-reactive VOCs usually measured indoors [117].

An exposure limit of 450 μg/m^3 was recommended by the EU-INDEX project [70]. However, it was stated that it was not possible to recommend this limit as a guideline value for d-limonene due to the lack of sufficient toxicological data.

Measurements of indoor concentrations of limonene in schools in the framework of the SINPHONIE project show values ranging from 0 to 671 μg/m^3. Indoor limonene levels in schools were significantly higher in SINPHONIE Cluster 3 (Central-Eastern Europe) than in Cluster 4 (Southern Europe) and Cluster 2 (Western Europe), and were very low in Cluster 1 (Northern Europe). With the exception of two classrooms, the majority of children were exposed to very low levels of limonene (i.e. less than 100 μg/m^3) (50th percentile, 9.3 μg/m^3; 90th percentile, 100.9 μg/m^3).

5.1.2 Microbiological agents

The role of microbes in human health and disease is ambiguous, as both adverse and beneficial effects are known. This is also true in the context of microbes as indoor air contaminants, where protective effects of exposure to elevated levels of microbial agents have been reported in many "farming" studies, while adverse health outcomes are typically reported in connection with conditions of indoor dampness and associated microbial proliferation. Considering adverse health effects due to elevated microbial exposures, it should be clearly stated, however, that while the association between indoor moisture and dampness and health effects is well established (WHO guidelines on dampness and mould

[124]), the involvement of microbes in this phenomenon has not been convincingly shown, and the proof of causality is lacking.

Nevertheless, there is good evidence that microbial agents indoors are involved in adverse health outcomes. The school environment may be particularly important in this context, as for endotoxin, for example, it has been shown that exposure in classrooms clearly exceeds exposure in the home environment [54, 96]. It is likely that similar trends can also be observed for other microbial contaminants. Some countries have implemented guideline values for viable moulds or bacteria in the indoor air, although these guidelines are not health based. They have rather been developed to provide a tool to detect situations of moisture damage and dampness and associated microbial proliferation indoors and are based on findings showing moisture and mould damage indoors. Health-based guidelines for microbes are unlikely to be established due to the huge diversity and variation of microbial spores, cells, fragments and metabolites and to differences in responses among individuals. In SINPHONIE, it was a step forward to sample and analyse microbial agents using state-of-the-art approaches that we believe are suitable to replace traditional, cultivation-based methods for the enumeration of viable microbes in short-term air samples. Rather than simply trying to make comparisons with the few existing national guideline values on the basis of sub-optimal sampling and analysis techniques, SINPHONIE tried to provide a basis for the future development of guidelines by establishing an extensive dataset of microbial compounds measured using molecular methods in settled dust from a large number of classrooms in schools across Europe.

A classical risk assessment in the sense of identifying the population exposed above a certain threshold value was not therefore performed. Instead, we summarise and highlight some of the health associations found for microbial agents in the SINPHONIE dataset and provide data on exposure distribution to these agents among schoolchildren. Table 46 summarises the significant inverse associations between elevated microbial agents and (respiratory) health symptoms among SINPHONIE schoolchildren and teachers, and clinical measurements in the case of FeNO.

Endotoxin is a known inflammatory agent and respiratory irritant and for these reasons has been targeted in many home studies on asthma and allergy. Endotoxin in Dutch schoolchildren was linked to asthma-like symptoms in a recent study [54]. In SINPHONIE, irritation symptoms among schoolchildren and kindergarten children were linked to elevated levels of endotoxin. Moreover, doctor-diagnosed asthma, runny/blocked nose ever, nasal allergy, and cough symptoms in children were linked to high endotoxin levels in schools.

Aspergillus versicolor was linked to sore throat and feeling cold/feverish in schoolchildren and to wheezing and cough episodes, partly confirming the outcome of earlier studies [96, 10]. Elevated levels of *Alternaria alternata* showed significant associations in teachers with wheezing and asthma in the last 12 months, and were also linked to elevated levels of FeNO, a marker of lung inflammation.

Two bacterial groups targeted in SINPHONIE were linked to runny nose, irritative cough and dry throat among schoolchildren and kindergarten children. *Streptomyces* spp. was linked to wheezing and cough/phlegm episodes in teachers. *Streptomyces* spp. have been linked earlier to respiratory symptoms in pupils in Malaysian schools [9].

Table 46. Overview of health outcomes assessed via questionnaire or clinical measurements (FeNO) and significantly ($p<0.05$) associated with various microbial agents in SINPHONIE

	Schoolchildren	**Kindergarten children**	**Teachers**
Endotoxin	Eye irritation, dry throat, irritative cough Doctor-diagnosed asthma, runny/blocked nose (ever), nasal allergy, night dry cough, cough episodes	Hand rash, eye irritation Phlegm episodes	
Fungal species/groups			
Aspergillus versicolor	Sore throat, feeling cold/feverish		Wheezing, cough/phlegm episodes
Alternaria alternata			Wheezing, asthma (<12 months); FeNO ↑
Bacterial groups			
Streptomyces spp.		Irritative cough	Wheezing, cough/phlegm episodes
Mycobacterium spp.	Runny/blocked nose (ever)	Runny nose, dry throat	

Table 47 provides an overview of the exposure distribution of schoolchildren to endotoxin in SINPHONIE schools. While it is evident that a potential health risk is also linked to exposure to other microbial agents, we choose here to show the exposure distribution for endotoxin only, as endotoxin was sampled and measured in a standardised and potentially easily replicable way using the passive collection of airborne settled dust with an electrostatic dust fall collector for four weeks, and endotoxin activity was determined via the Limulus Ameobocyte Assay (see Methods section of this report). Some 10% of schoolchildren were exposed to over 24,000 endotoxin units in dust settled on 1 m^2 of electrostatic cloth in four weeks in SINPHONIE classrooms.

In future efforts to provide standardised approaches to monitoring microbiological agents in the indoor air, it is recommended to use simple, readily reproducible sampling methods, such as the electrostatic dust fall collector used in SINPHONIE, for the determination of endotoxin in airborne settled dust. Such a sampling approach, if carried our properly, could be comparable to the diffuse sampling approaches that are commonly used to determine chemical parameters in the indoor air. As for analysis techniques, cultivation-independent molecular approaches are to be favoured over cultivation techniques, as non-living microbial material is also relevant for human health.

Table 47. Distribution of exposure to endotoxin measured from airborne settled dust in SINPHONIE schoolchildren

Min., percentiles, max.	Endotoxin (EU/m^2)
Minimum	496
10^{th} percentile	2,181
25^{th} percentile	4,529
50^{th} percentile	7,460
75^{th} percentile	11,951
90^{th} percentile	24,353
Maximum	59,000

In conclusion, the studies conducted in the SINPHONIE project show that schools may frequently have IAQ problems, as various air pollutants can be found in classrooms sometimes in elevated concentrations. More specifically:

- *$PM_{2.5}$*: 13% of SINPHONIE schoolchildren were exposed at levels higher than 25 µg/m^3 (WHO ambient guideline as 24-hour mean) and more than 85% at levels higher than 10 µg/m^3 (WHO ambient guideline as annual mean), which are proposed in order to reduce the risk of long-term effects on cardio-vascular-respiratory function and lung cancer mortality.
- *Benzene*: about 25% of SINPHONIE schoolchildren were exposed to benzene in schools at more than 5 µg/m^3, which is the limit set by the Air Quality Directive (2008/EC/50) for the management of the excess lifetime risk of leukaemia. Based on unit risk estimations in the WHO air quality guidelines, the benzene median exposure level observed in SINPHONIE is linked to a risk level of 1.3 x 10^{-5}, and an excess lifetime leukaemia risk of 1: 76,923 in the total population studied, as well as a risk level of 2.0 x 10^{-5}, corresponding to an excess lifetime leukaemia risk of 1: 50,000 in schoolchildren from Central-Eastern European countries.
- *Formaldehyde*: more than 60% of children were exposed to formaldehyde in schools at more than 10 µg/m^3 (proposed by AFSSET as a long-term indoor air guideline value to protect from long-term effects), with the highest median levels in Central-Eastern and Western countries.
- *Radon*: 50% of SINPHONIE schoolchildren were exposed at more than 100 Bq/m^3 (national residential reference proposed by WHO in 2010 to manage excess lifetime risk of radon-induced lung cancer).

The available studies do not provide information about levels of contamination by microorganisms that could be useful for health risk assessment. In the SINPHONIE project, we have tried to take a step forward and to sample and analyse microbial agents using state-of-the-art approaches that we believe are able to replace traditional, cultivation-based methods for the enumeration of viable microbes in short-term air samples in order to provide a basis for the future development of guidelines by establishing an extensive dataset on microbial compounds measured using molecular methods in settled dust from a large number of classrooms in schools across Europe. Although median values were low in some cases, 50% of children and teachers were exposed to high levels of endotoxins and microbes. These results indicate that fungi common in damp buildings are more abundant than those typically found outdoors. There are no EC limit values or WHO guidance to compare against the bio-contaminant level measured in SINPHONIE schools, and national guidance exists in only a few countries.

5.2 Gaps in knowledge and recommendations

In the context of the SINPHONIE project, indoor air pollutants have been found in school classrooms often in concentrations higher than outdoors. Schools may have severe IAQ problems because of location/exposure to traffic, inappropriate building design, construction, operation and maintenance, poor cleaning and inadequate ventilation. Building construction, decoration and furnishing materials, the degradation of walls and ceilings as a result of water infiltration and the production of fungi and mould, as well as occupants' activities (smoking, the use of cleaning products, cleaning activities, painting and sticking activities and the use of do-it-yourself products) constitute important sources of indoor pollution in schools. In addition, the outdoor environment, with its traffic-related or industrial pollution, as well as the ground on which the school buildings are constructed, are a major source of some indoor air pollutants found in schools (e.g. $PM_{2.5}$ and benzene).

Indoor air quality in schools should therefore be recognised as a priority topic for public health. A multidisciplinary European programme on IAQ that gives particular attention to schools is required and recommended, with the aim of encouraging and coordinating actions in the fields of prevention, information, education, training, research and legislation related to the school environment.

The development of a multidisciplinary programme for good indoor school environments is needed in order to promote:

- *initiatives*, including legislative initiatives, to regulate school buildings in terms of design, construction, materials used (e.g. carpets and other textile materials), cleaning and building maintenance procedures; to ban tobacco smoke; to contribute to the avoidance of allergens; and to enhance the implementation of health-based ventilation strategies;
- *awareness campaigns and training* aimed at children and their families, school staff, professionals, policy and decision makers and the public; and
- *research* to develop sustainable measures to improve IAQ in school buildings.

This multidisciplinary programme should lead to:

- the adequate management of pollution from the outdoor air/exposure to traffic;
- the avoidance of environmental tobacco smoke and low-level indoor sources of VOCs;
- adequate radon prevention and mitigation strategies;
- the avoidance of moisture/mould and allergen sources in school buildings;

- adequate cleaning and maintenance and the practical shaping of the school building interior to facilitate cleaning and maintenance;
- good control and maintenance of heating and ventilation to ensure satisfactory temperature, relative humidity and ventilation in classrooms;
- the periodical monitoring of IAQ and health parameters in schools; and
- the appropriate training of students, teachers and school staff who are responsible for the management, maintenance and cleaning of school buildings.

Further research is needed to develop sustainable measures to improve IAQ in school buildings, in particular on:

- the impact of IAQ in schools on health and its effects on children's learning performance and life styles; and
- the implementation of an epidemiological methodology including:

  - IAQ audits in schools for the main IAQ indicators ($PM_{2.5}$, VOCs, formaldehyde, radon, bio-contaminants, ventilation), in combination with an evaluation of school building characteristics and school building use; and
  - standardised questionnaires, medical visits and objective clinical tests to establish a system of medical surveillance and the health screening of schoolchildren and school staff.

6 Guidelines for Healthy Environments within European Schools

To reach the objective of healthy school environments in Europe, an integrated and holistic approach is needed, including guidelines and recommendations on prevention, control remediation and communication strategies, covering a wider array of situations in Europe and addressing IAQ (the chain from exposure to potential causes and sources, health risk assessment, strategies and policy options) in schools along with their location, design, construction, use, management and maintenance.

In the context of SINPHONIE, reference guidance was produced that links together, in a coherent and comprehensive way, the most up to date information enriched by the outcomes of SINPHONIE concerning key drivers and prevention, control, remediation and communication strategies for healthy school environments in Europe.

This guidance is intended to provide advice that can be regarded as generally applicable in most school environments in Europe. However, as each school environment is unique (in terms of design, climatic conditions, operational modes, etc.), the guidance needs to be adapted as appropriate at national or local level. To this end, criteria for the take-up and implementation of the guidance into national policy measures and actions in European countries are also provided. The SINPHONIE guidelines are not therefore intended to replace, but rather to enrich and reinforce, existing national and local guidance that should continue to be the first point of reference.

It should be underlined that these guidelines promote a preventive and cost-effective approach, in terms of the efforts and associated costs required to achieve good IAQ in a given school environment, as opposed to a problem-based approach that seeks to solve problems after they have emerged.

The guidelines for healthy environments within European schools are primarily directed to relevant policy makers at both European and national level and to local authorities aiming to improve the indoor school environment in their countries while respecting the specificities (environmental, social, economic) of their national and local situations. A second target group that is expected to benefit directly from these guidelines includes school building designers and managers (responsible for the design, construction and renovation of school buildings), schoolchildren and their parents, teachers and other school staff.

Overall, and in the context of a pragmatic centripetal movement (from outdoors to indoors, from the environment to the people, from sources and causes to health effects), the SINPHONIE guidelines for healthy school environments in Europe underline that, in future strategies and policies relating to the school environment, priority should be given to pollution source control that takes the following aspects into consideration:

Location

Aspects to be considered include:

- the proper management of urban pollution, particularly pollution from outdoor air and its major sources (e.g. transportation and traffic);

- better control over the quality of the outdoor air that enters the school indoor environment by choosing “pollution-free” zones for new schools, by promoting compliance with the WHO guidelines for ambient air near existing schools, and, consequently, by imposing stricter measures to improve traffic conditions in the vicinity of schools (e.g. within a radius of 1 km);
- adequate radon prevention and mitigation strategies.

Building design, construction (including retrofitting) and maintenance

Aspects to be considered include:

- the proper design and construction of school buildings and the selection of clean materials for new and retrofitted schools by integrating energy, indoor air and comfort requirements into a holistic assessment at the school building design and post-occupational phases;
- the avoidance of moisture/mould and of allergen sources in the school building;
- an appropriate strategy for heating and, where necessary, cooling, to ensure satisfactory temperature, relative humidity and ventilation in classrooms;
- the decoupling, as far as possible, of heating/cooling functions from the ventilation function; and
- the establishment of ventilation levels based on health criteria measurable in litres per second per person (l/s.person).

Management and use

Aspects to be considered include:

- the definition and enforcement of limits for maximum permitted occupation densities in classrooms to ensure appropriate levels of CO_2 with acceptable and affordable ventilation rates;
- the periodical monitoring of IAQ and health parameters in schools;
- the establishment of a manual of procedures for properly using and managing the school indoor environment, in particular IAQ;
- ensuring appropriate cleaning and maintenance of school buildings;
- the selection of low-emission products for cleaning practices as well as materials used in school activities and didactic materials;
- the appropriate training of students and their parents, teachers and school staff responsible for the management, maintenance and cleaning of school buildings;
- the development and implementation of harmonised methodologies and protocols for IAQ assessment at different levels of complexity and/or exigency in European countries; and
- ban the use of environmental tobacco smoke in all school spaces.

The full content of the SINPHONIE guidelines for healthy environments within European schools was published separately (annex 7).

7 Main Conclusions and Future Outlook

The SINPHONIE project, funded by the European Parliament and carried out under a contract with European Commission's DG SANCO, was the first Europe-wide pilot project to monitor the school environment and children's health in parallel in 23 European countries. The project brought together the multidisciplinary expertise of 38 partners (plus one associated partner) from 25 countries. One of its main objectives — to collect information on IAQ and children's health from schools throughout Europe using comparable methodologies — was successfully achieved. SINPHONIE contributed to the fulfilment of the Parma WHO Ministerial Declaration commitments [122] in terms of policy development and environmental health actions for children.

Overall, SINPHONIE can be considered as a milestone project that provided standardised methodologies and tools, provided health risk methodologies and elaborated guidelines and recommendations for healthy school environments in Europe. At the same time, it represented a unique opportunity and an excellent vehicle for capacity building for several national institutions mostly in Eastern and Southern European countries. In this sense, it has been a clear case of "technology transfer" concerning IAQ and health impact assessment methodologies in European countries.

The outcomes of the SINPHONIE studies underline the importance of IAQ in schools as a societal problem with clear impacts on the health, quality of life and learning performance of schoolchildren in Europe.

New exposure data were generated, unique in terms of wide European coverage and enhanced data comparability due to the use of harmonised protocols and tools. Related information on school buildings/classroom characteristics was gathered that made it possible to study the interactions between IAQ and pollution sources in the school environment. All the standardised tools developed and used within SINPHONIE represent important outputs that can be further used in similar multi-centre studies and routine controls. In this context, the SINPHONIE database represents an important starting point for a systematic gathering of comparable air quality and health data to feed future polices related to the school environment at both national and EU levels.

The findings of the SINPHONIE project show that asthma at school may affect 100,000 children in Europe, and the SINPHONIE monitoring revealed that: (a) the prevalence of diagnosed asthma, nasal allergy and eczema was 8%, 9% and 17% respectively; (b) among all SINPHONIE schoolchildren the commonest recent (<3 months) health event was a blocked nose (47%) followed by a runny nose, feeling cold or feverish, headache, feeling tired and sore throat (36%); and (c) 26% of the children felt better after returning home.

In addition, smoking still takes place in 5% of the schools monitored in SINPHONIE, 67% of the schools are affected by nearby traffic, and about 20% of all schools are operating with occupation densities lower than 2 m^2/child, leading to undesired levels of CO_2 in classrooms (which translates into a requirement for unreasonably high levels of ventilation).

Commonly encountered indoor air pollutants in schools are $PM_{2.5}$, VOCs such as limonene, formaldehyde, radon and biological agents. These air pollutants were monitored in classrooms sometimes in elevated concentrations, often higher than outdoor levels and above existing guideline values proposed by EU and WHO. This results in inadequate IAQ in school buildings, which can have a negative impact on the health, attendance and performance of children, teachers and school staff.

Indoor air quality in school buildings is shown to be a complex function of outdoor air pollution, school building characteristics, operation and management practices, including cleaning, maintenance and ventilation strategies. The use of paints, glues and other school and products for didactic purposes are among the important sources of indoor pollution in school buildings.

It is clear that school buildings are critical as they are designed and built for children, who are a particularly susceptible segment of the population to certain health determinants such as those relating to IAQ. Some of the findings that emerged during SINPHONIE underline the relevance of the issue of schools as buildings, most of which were built in the 1990s or earlier. Although 60% of the school buildings in Europe have been retrofitted to some extent since then, they are typically far from being considered as healthy, and this remains a priority challenge for future policies at both EU and national levels. This sometimes leads to an overemphasis on the need for ventilation, heating or cooling, and even to a failure to consider the potential impact of climate change.

Climate change and global warming are unquestionable. Their impact has been the subject of many worldwide studies, which estimate a temperature rise in Europe of up to 2 or 3ºC in the space of two generations. However, the results of the SINPHONIE field studies show that, despite some significant differences in indoor temperatures, depending on the geographical location of the schools and on the circumstance of having more or less adequate heating/cooling systems, the mean temperature values observed during the heating period were quite similar (around 20ºC), regardless of the region where the school buildings were located. Consequently, any concerns about potential overheating in school buildings should first be weighed against the fact that schools do not operate during the two warmest months of the year. Concerning the impact of traffic, it is clear that related pollutants such as $PM_{2.5}$, NO_2, ozone and noise contribute to the indoor air pollution load in schools especially in the case of those located in the proximity of busy roads, thus affecting 67% of all schools monitored. There seems to be an interplay between two factors here. One is related to the age and location of many school buildings in European countries, which were planned and built when roads were less busy and promised the benefit of easy accessibility, while potential future trends in pollution were overlooked. The second is related to urban pollution itself, undoubtedly mainly due to traffic, but not exclusively. As the issue of IAQ in school buildings cannot be properly addressed if the quality of the ambient air is ignored or overlooked, it is essential that the local/national authorities that manage ambient air quality in their urban environments maximise their efforts to ensure that the ambient air respects the WHO air quality guidelines.

To ensure the appropriate and efficient implementation of the guidelines and recommendations elaborated within SINPHONIE and aimed at healthy school environments in Europe, the following points should be given particular attention:

- The issue of good IAQ in schools is very much dependent on their location, as the outdoor air is a major source of indoor air pollution. Consequently, in line with other policy trends at the EU and WHO region levels, it is necessary to state in the present context the recognised importance of ensuring that ambient air quality in cities meets WHO air quality guidelines. Only then can proper IAQ be expected in buildings in general, and thus also in school buildings.
- No new school buildings should be built without taking into account advances in construction technologies and IAQ strategies, starting with source control through clean materials and construction products, to the decoupling of heating/cooling functions from health-based ventilation. Due consideration must be given to climate and geography, along with the related materials and culture, ensuring a holistic approach to sustainability and giving precedence to sufficiency over efficiency whenever the management of resources is at stake.
- Priority should be given to simple but sound rules, free from technical buzzwords, social prejudices and cultural conditions, leading to appropriate school building management procedures that take into account the adequate knowledge and specificity of the actual building in its actual location and the proper use of resources (water, energy, educational materials, cleaning products, cleaning procedures, etc.) by approaching each school building as an actual children's "second skin" for many hours during a vulnerable period of their lives.
- Awareness-raising campaigns and training should be provided for children and their families, school staff, professionals, policy makers and the general public. SINPHONIE brochures for schools were prepared that provided tips and recommendations for a healthy school environment in Europe in 20 languages (www.sinphonie.rec.org). Decision making based on technically inadequate solutions, naïve interpretations and interventions weakly linked to scientific merit and foundations is the main reason behind poor IAQ in European schools, as highlighted by SINPHONIE. The excellent cooperation between EU and WHO Europe, and the follow-up of promising political declarations (such as the declaration following the Parma WHO Ministerial Conference in 2010) [122], will be meaningful only if the consistent steps, developments and recommendations set out in this report are taken on board.
- The complexity of the interrelations between physical, chemical and biological factors, exposures, sources/causes and health impacts among schoolchildren, which has been illustrated by the SINPHONIE outcomes, needs to be further and deeply investigated in order to efficiently protect children from a wide range of health effects associated with poor air quality in the school environment.
- There is a need to integrate exposures occurring in the school environment with home pollution loads, as children spend more than 60% of their time at home, and also to elaborate and implement holistic and cost-effective approaches concerning prevention, control, and remediation and communication strategies for achieving healthy school environments in Europe. In terms of communication, the SINPHONIE outcomes will be widely disseminated to policy makers at EU and

national levels, local authorities, school building designers and managers, schoolchildren and their parents, teachers and other school staff.

The outcomes of the SINPHONIE project and potential follow-up activities can therefore greatly contribute to realising the aspirations expressed during the important EU initiative, the 2013 Year of Air for Europe, relating to the promotion of healthy and sustainable lifestyles in Europe.

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Annexes

These are not published with this report but can be obtained on request.

They are also available on the project website (www.sinphonie.rec.org).

Annex 1	Document related to project and consortium management
Annex 2	Background report
Annex 3.1	School and classroom checklist
Annex 3.3	Protocol for physical and chemical measurements
Annex 3.6	Report on the results of the main study and the case studies
Annex 3.7	Protocol for biological tests – Main study
Annex 3.9	Datasets from vacuumed floor dust
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Annex 3.11	Datasets from qPCR indoor and outdoor
Annex 3.12	Report on the biological study
Annex 4.1	SINPHONIE questionnaires
Annex 4.2	Assessment of absenteeism
Annex 4.3	Protocol for performing clinical tests
Annex 4.4	Protocol for attention/concentration tests
Annex 5.	Results on health outcomes and indoor exposure, 5.1, 5.2
Annex 5.	Data management, 5.3 to 5.5
Annex 6	Documents related to health risk assessment
Annex 7	Guidelines for Healthy School Environments in Europe
Annex 8	Documents related to communication and dissemination

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