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SynAir-G

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SynAir-G

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SynAir-G

Table of Contents

Specifications for sources identifications 1

Air Pollution sources identification 5

Objective assessments 5

Outdoors 5

Indoors 6

Without objective assessments 7

Development of a School Exposure Matrix (SEM) of air and dust pollutants 9

Abstract 10

Introduction 11

Material and methods 14

Results 16

Quantifying exposure to sources and related air pollutants 26

Discussion 26

Conclusion 28

References 29

Perspectives 33

Air Pollution sources identification

One of the main objectives in the frame of the SynAir-G project consists in the identification of air pollution sources in the schools.

This involves a combination of methods and technologies to determine the origin and composition of air pollutants that depend on the availability of objective assessments of air pollutants and comfort parameters.

Objective assessments

Here are the specifications and techniques elaborated under the supervision of a panel of experts for outdoor and indoor air pollution source identification when objective assessments are available.

Outdoors

1. **Air Quality Monitoring Stations:**
    - Identification of monitoring stations across an area strategically close the targeted buildings (schools, houses).
    - Collection of measure concentrations of key air pollutants, including particulate matter (PM), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and volatile organic compounds (VOCs).
2. **Emission Inventories:**
    - Identification of comprehensive inventories of emissions from various sources, including industrial facilities, transportation, residential heating, and agricultural activities.
    - Collection of other data such as fuel consumption, industrial processes, and other relevant parameters directly or indirectly related to air pollution emissions.
3. **Remote Sensing Techniques:**
    - Use of satellite and aerial imagery to detect and monitor pollution sources from above.
    - Use of remote sensing data to identify industrial facilities, traffic patterns, and land use.
4. **Chemical Analysis:**
    - Identification of existing chemical analysis of air samples to identify specific pollutants and their chemical composition. Techniques may include gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC), and others.
5. **Meteorological Data:**
    - Consider meteorological data to understand how atmospheric conditions influence pollutant dispersion.

- Collect data on wind speed, direction, temperature, and atmospheric stability as crucial parameters.

6. **Dispersion Modeling:**
   - Use of dispersion models to assess the spread and concentration of pollutants from specific sources.
7. **Source Apportionment Studies:**
   - Conduct source apportionment studies to identify the contribution of different sources to overall pollution levels.
   - Use statistical methods, receptor 6odelling, and data fusion techniques.
8. **Mobile Monitoring:**
   - Deploy mobile monitoring units to track pollution levels in different locations and identify hotspots.
9. **Community Engagement:**
   - Involve the community in identifying potential pollution sources through citizen science initiatives.
   - Gather local knowledge and observations to complement technical data.
10. **Continuous Monitoring Networks:**
    - Establish continuous monitoring networks to provide real-time data for timely identification of pollution events.

Indoors

1. **Indoor Air Quality (IAQ) Monitoring:**
   - Utilize IAQ monitors to measure concentrations of indoor pollutants such as volatile organic compounds (VOCs), particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO2), and others.
   - Place monitors in key locations to capture variations in pollutant levels.
2. **Ventilation System Inspection:**
   - Assess the design and condition of ventilation systems.
   - Check for proper ventilation rates and air exchange efficiency.
   - Identify and address potential sources of contamination within ventilation systems.
3. **Building Materials Inspection:**
   - Identify and evaluate the materials used in building construction and furnishings.
   - Some classroom and home materials release VOCs over time, contributing to indoor air pollution.
4. **Occupant Activities and Habits:**
   - Consider the activities of occupants, such as cooking, smoking, and the use of household products.
   - Understand daily habits that may contribute to indoor pollution.
5. **Mold and Moisture Inspection:**
   - Inspect for water leaks, moisture issues, and mold growth.
   - Mould spores can significantly impact indoor air quality.

6. **Radon Testing (when appropriate):**
    - Conduct radon testing, especially in areas with high radon potential.
    - Radon is a colorless, odorless gas that can seep into buildings from the ground.
7. **Combustion Appliance Inspection:**
    - Inspect combustion appliances (e.g., gas stoves, heaters) for proper installation and ventilation.
    - Ensure appliances are well-maintained to prevent the release of harmful combustion byproducts.
8. **Formaldehyde and Chemical Testing:**
    - Test for the presence of formaldehyde and other chemicals emitted from furniture, flooring, and household products.
    - Use specific detectors or air sampling methods.
9. **Particle Counting:**
    - Employ particle counters to measure the concentration of airborne particles in different size ranges.
    - Identify sources of particulate matter, such as dust or combustion byproducts.
10. **Humidity and Temperature Monitoring:**
    - Monitor indoor humidity levels to prevent conditions conducive to mold growth.
    - Maintain appropriate temperature and humidity for occupant comfort and health.
11. **Indoor Air Quality Surveys:**
    - Conduct comprehensive surveys to gather information on occupant well-being, comfort, and concerns.
    - Use surveys to identify patterns and potential sources of indoor pollution.
12. **Occupant Interviews:**
    - Interview building occupants to gather insights into their experiences and perceptions of indoor air quality.
    - Identify specific areas of concern and potential pollution sources.

To sum up, effective source identification involved a combination of these methods, integrating data from various sources to create a comprehensive understanding of air pollution patterns and sources both indoors and outdoors.

Without objective assessments

However, very often it is not possible to hold objective assessments of air pollutants and air pollution sources are assessed based on other tools. This was the case of the SynAir-G projects in which we implemented:

1) comprehensive surveys to gather information on the environmental characteristics of the studied site (classrooms, house, hospital, etc.)

2) and, in analogy with the Job Exposure Matrix (JEM), a School Exposure Matrix (SESM) of air and dust pollutants.

This double approach is summarized in the paper entitled "**Development of a School Exposure Matrix (SEM) of air and dust pollutants**" herewith enclosed, to be submitted to a peer-reviewed journal in the short time.

Development of a School Exposure Matrix (SEM) of air and dust pollutants

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Abstract

Knowledge in the field of environmental exposure to air and dust pollutants is constantly evolving and expanding. Strong evidence exists in literature about the presence of certain air and dust pollutants (gases, particulate matter, volatile organic compounds, phthalates), their sources and their association with health outcomes, but we do not yet have, except for the occupational exposure field, many models available that allow to associate a precise exposure with a given source with certainty, in particular for the exposure of the pediatric population.

For this very reason, one of the purposes of the EU SynAir-G project was to develop a novel School Exposure Matrix (SEM) applicable to the schoolchildren population, identifying pollutants in the air and dust, in the school environment so to make it possible to recognize for each toxicant the possible sources and *vice versa*. The matrix consists of a y-axis corresponding to the pollutants and an x-axis corresponding to the sources of exposure eventually related to the pollutants; the exposure metric (low, medium or high) was estimated as the intensity of exposure combined with time of exposure. SEM was developed and validated by a panel of experts.

Besides the better known sources of indoor and outdoor air pollutants like industrial pollution, gas burning, domestic combustion and road traffic (nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and particulate matter (PM)), the matrix includes a variety of possible sources of indoor and outdoor exposure to emergent airborne pollutants found in schools, particularly with regard to the category of Volatile Organic Compounds (VOCs), Semi-volatile VOCs (SVOCs), Non-Volatile compounds and Microbial VOCs (MVOCs), sourced by objects commonly used in indoor environments: cleaning and personal hygiene products, books, toys, furniture and office supplies, in addition to the structural elements of the building, its state of preservation and the characteristics of its interiors.

The School Exposure Matrix (SEM) is intended to result in a useful tool for learning about the school environment that surrounds schoolchildren and the exposure they are subjected to in their school activities.

Keywords: air pollution, dust, indoor and outdoor environment, school, home, exposure, matrix.

Introduction

Pollution of the air we breathe every day is now for all intents and purposes recognized as a worldwide problem, with obvious and known repercussions on human health; in particular, an increased risk of cardio-vascular, respiratory (COPD, asthma, basic airway infections) and neoplastic diseases. The impact is even greater in the case of low socio-economic conditions, in low- and middle-income countries and in overcrowded conditions, and in the case of the pediatric population. The WHO has estimated a number of 12.6 million deaths worldwide due to environmental pollution, representing 26% of young children's deaths.

Airborne pollutants encompass air pollutants like gases (nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO) and volatile organic compounds (VOCs)), and Particulate Matter (PM) but also other pollutants contained in the dust, as indicated below, that may float in the air when air moves. Strong evidence exists on their connection with principal sources like industrial pollution, gas burning, domestic combustion and road traffic, and their health impact; nevertheless, emergent toxicants with sources found in environments that are part of everyday life are also important because of their potential effect on human health. They include Volatile organic compounds (VOCs), semi-volatile VOCs (SVOCs), like phthalates (PAEs) novel brominated flame retardants (NBFRs), organophosphate flame retardants (OPFRs) and polychlorinated biphenyls (PCBs) (Table 1). To these, have to be added non-volatile compounds like Per- and polyfluoroalkyl substances (PFAS) (Table 1).

Table 1: Different types of organic compounds

VOCS	Chemical characteristics	Examples
• **Volatile Organic Compounds (VOCs):**	These have high vapor pressures and can easily evaporate into the air at room temperature.	Formaldehyde, benzene, toluene, etc.

• **Semivolatile Organic Compounds (SVOCs):**	These have intermediate vapor pressures and typically have higher boiling points than VOCs. SVOCs include compounds that can evaporate but are more likely to be found in the particle phase or on surfaces.	Phthalates (PAEs) novel brominated flame retardants (NBFRs), organophosphate flame retardants (OPFRs) and polychlorinated biphenyls (PCBs)
• **Non-volatile Compounds:**	These have low vapor pressures and do not readily evaporate into the air.	Heavy metals, Minerals and Oxides, Plastics like polyethylene and polypropylene, Per- and polyfluoroalkyl substances (PFAS)

Health effects of emergent pollutants are poorly known. PAEs are beginning to be recognized as impacting human growth and reproductive health in several studies, going on to create hormonal imbalances with multifaceted consequences and meanings that are not yet fully clinically defined. However, other health effects are recognizable, such as insulin resistance and type 2 diabetes, allergy and asthma, obesity and skeletal anomalies.

Besides chemical pollutants also biocontaminants and related microbial volatile organic compounds (MVOCs) released by microorganisms, such as bacteria and fungi, into the air are of importance. These compounds can have distinctive odors and play various roles in microbial interactions, communication, and ecological functions.

Children suffer more than adults from exposure to air pollution both outdoors and indoors. This is due to their developing immune and respiratory systems, higher breathing rates, type of activities and longer life expectancy post-exposure.

Children, especially in urban areas, may live in environments with higher concentrations of air pollutants due to factors like proximity to busy roads, industrial areas, or poor housing conditions. In addition, children spend up to 10 hours a day indoors, particularly at school after their house, thus making the schoolchildren population extremely susceptible to the harm of airborne pollutants on future development and health. The impact of the school environment is crucial on the health and performance primarily of the schoolchildren, but also of all those professionals who frequent this environment on a daily basis, namely teachers, administrative staff, janitors and cleaning staff.

The school environment is a less studied and known environment than the adult work environments, in spite of the fact that it is particularly exposed to indoor pollution, is one of the most frequented environments by children and for a continuous time, and is also affected by the characteristics of outdoor pollution (location of the school/classroom near busy roads, traffic lights, industries and/or farms, etc.). All of these, together with the building characteristics, the state of structural maintenance of the building, the characteristics of the ventilation within it, and the quality of the furniture used, create a peculiar and independent heterogeneous microenvironment that must be carefully studied.

In the frame of the EU SynAir-G project, the aim of the present work was to implement a School Exposure Matrix (SEM) of hazards in schools and classrooms, air and dust pollutants in particular as the commonest, as a tool to be used in environmental epidemiology to assess and quantify exposure to these contaminants according to various sources and to link sources exposures with health outcomes in school occupants. Particular attention was given to emergent airborne pollutants found in schools, particularly with regard to the category of Volatile Organic Compounds (VOCs) like formaldehydes and benzene, Semi-volatile VOCs (SVOCs) like phthalates and flame retardants, and Microbial VOCs (MVOCs). SEM takes into account the fact that there is a dynamic relationship between outdoor and indoor pollution. Outdoor pollutants, such as particulate matter, O_3, NO_2, and VOCs, can infiltrate indoor spaces through open windows, doors, and ventilation systems. Some outdoor pollutants can react with indoor materials, such as carpets, furniture, and paints, leading to the release of secondary indoor air pollutants.

Material and methods

Study design

The SynAir-G project [https://synairg.eu/] was initiated with the desire to reveal and quantify synergistic interactions between different pollutants in the air and the dust affecting children's health, focusing on the indoor pollution in school setting in view to develop a comprehensive and responsive multipollutant monitoring system and promote environmentally friendly interventions and knowledge to protect schoolchildren and other schools' occupants. To achieve these objectives, one of the specific objectives of SynAir-G is to provide data on air and dust pollutants and their sources in schools of 5 countries around Europe.

However, in SynAir-G, the air and dust pollutants that were objectively assessed are limited in number and time. Only major air pollutants and phthalates found in the dust were assessed and for limited periods.

In order to develop precision technologies for detecting more exhaustively contaminants and achieve results informative in terms of type of compounds, in the absence of objective assessments that cost time and money, there is a need for the development of a tool able to identify possible sources within a given environment in a timely manner and to relate them to the types of contaminants produced.

SynAir-G paved the way to create the School Exposure Matrix (SEM), both in order to identify and highlight any harmful substances to which children of primary school are exposed and also in order to educate and enable all those who frequent these environments on a daily basis to the existence of potential hazards. A panel of experts, partners of the SynAir-G projects, participated to the SEM implementation and validation.

Checklists

The first step was to collect information on possible sources of exposure in the primary school environment adapting existing standardized and validated instruments.

To this extent, were used checklists already compiled as part of two population-based surveys on the impact of long-term and short-term environmental exposures on children's health, namely the SINPHONY and the European pilot survey on exposure and health examination (EXHES) of children carried out as part of the HEALS (Health and Environment-wide Associations based on Large population Surveys) project.

EXHES checklist A and checklist B developed to best study the indoor environment, were aimed at finding information related to different types of indoor sources: factors related to energy sources used for heating and cooking (biomass, gas, etc.), possible allergens and sources of microbial agents (pets, indoor plants, carpets and rugs), type of products used for cleaning and disinfection, for do-it-yourself and others activities (painting, using glues, etc.), and tobacco smoking habits (second-hand and third-hand smoke). In addition to all this, the structural and geographical characteristics of the building and rooms were also taken into consideration as well as to the type of ventilation and aeration. They were used in SynAir-G to identify schools and houses sources of contaminants.

Development of the School Exposure Matrix (SEM)

The panel of experts decided to implement a School Exposure Matric (SEM) in analogy with the Job Exposure Matrix (JEM).

A matrix is a tool of quick and easy reference in order to identify the relationship between two (or more) variables of interest. In the medical literature, the most famous is the job-exposure matrix (JEM), created in occupational medicine in order to be able to associate schematically for each type of work the exposures at risk, but also to be able to start from exposure to a particular substance (e.g., silica) in order to identify which workers may be exposed to it. Essentially, a JEM comprises a list of levels of exposure to a variety of harmful (or potentially harmful) agents for selected occupational job titles. In large population-based epidemiological studies, JEMs may be used as a quick and systematic means of converting coded occupational data (job titles) into a matrix of possible exposures, eliminating the need to assess each individual's exposure in detail.

In the literature, there is only one matrix applied to the world of environmental pollutants, which is not occupational; however, it focused solely on organic pollutants, the construction methods of which we have studied in order to be able to apply and implement our own, then integrating it with the notions of HEALS.

Starting from the information developed thanks to two of the EXHES experience inside HEALS (checklist A and checklist B), we implement the information on sources and contaminants by completing it through a literature review regarding all the sources traced.

All the indoor environment exposure factors associated with selected common indoor air pollutants were collected and sorted. The keywords used in searching for websites were linked to the possible sources of gaseous agents (NO_2, CO_2, CO, SO_2, O_3, PAHs, VOCs), particulate matter ($PM_{2.5}$, PM_{10}, Ultrafine Particles (UFP)), microbial agents (bacteria, viruses, fungi, mycotoxins, endotoxins), indoor allergens (dog and cat epithelium, cockroaches, mice, dust mite).

Then, thanks to the information obtained with that extrapolated from the EXHES checklists, a particular focus was carried out regarding the "new indoor air pollutants": endocrine's disruptors (phthalates, NBFRs, OPFRs, PCB, PFAS), other VOCs, SVOcs and mVOCs, as well as the role of outdoor air quality.

Finally, the potential impact of outdoor air pollution on indoor pollution was considered in the SEM implementation.

The panel of experts validated the matrix in a series of meetings where the following three steps were performed: 1) internal expert review and consensus; 2) external comparison with the literature; 3) cross-validation studies with actual exposure measurements were available from previous surveys.

Results

Below, we present all the potential sources and the related pollutants in schools.

Building characteristics

As is to be expected, the condition of the school building is critical in going to affect the quality of the air we breathe;

it became clear then that one must therefore assess the year in which it was built, both because of the fact that the older it is, the greater the possible emissions of NO_2, CO_2 and particulate but also to identify the use of some possible materials (for example, asbestos).

Another important element is the geographic location of the building: there are some areas that are naturally rich in radon, so emissions of this gas (a carcinogen that ranks second after tobacco smoke among causes of lung cancer) are to identify and manage.

The building's characteristics within schools such as physical defects (i.e., leaks in roof, broken windows, damaged walls, crack/fissuers in the building) are associated with increased indoor air pollution, especially with emission of NO_2, CO2, $PM_{2.5}$, VOCs and formaldehyde, spore molds and asbestos.

VOCs are a group of compounds including aromatic hydrocarbons, aldehydes, aliphatic halogenated hydrocarbons and terpenes. Even at low levels, VOCs may cause acute effects such as headaches and irritation of the nose and eyes; lowly correlation to wheezing in children. Formaldehyde is commonly found in homes, public buildings and schools, representing an important mucous membrane irritative agent with potential carcinogenic effect and formaldehyde exposure has been related to sensory irritation and asthma-like symptoms.

Poor air quality can also be a concern during the process of school renovation due to the release of toxic materials during demolition, dust and fumes from construction, and designs that interfere with ventilation; one among all, formaldehyde.

But generally, renovation appears to be beneficial in most cases for children's health, with a positive effect on stuffy nose, rhinitis, sore throat, hoarseness, cough, eye symptoms, and fatigue; of course, materials used inside for floors or walls has also impact on health too.

Persistent dampness in indoor environments represents a widely recognized indicator of health risk, namely to the development of asthma and respiratory symptoms (such as cough and wheeze). Moreover, dampness and mould are established as major IAQ problems which disproportionately affect the health of disadvantaged populations. Ideal relative humidity in indoor environment has to be between 30 and 50%

Dampness can be a source of formaldehyde, allergens (spore molds), bacteria, molds and fungi (*penicillum, fusarium, aspergillus, trichoderma, metarhizium, mucor pestalotiopsis, umbelopsis, aureobasidium pullulans, stachybotrys chartarum, alteraria alternata, cladosporium, epicoccum nigrum, mycotoxins*). In addition, radon and molds can be themselves sources of indoor pollutants and emit particulate, same as pollen and fungal spores

It should be remembered the importance of the temperature too, which is obviously influenced by the aforementioned characteristics of the building: the WHO recommends temperatures of 21 ◦C in the living rooms and 18 ◦C in other occupied rooms to achieve an adequate standard of warmth.

Furniture and decorations, textiles

Supplies and decorations are a major source of indoor air pollutants, especially when we talk about VOCs; naturally, depending on the type of material used in school furniture, we can have different emissions.

In general, furniture can be source of a diverse spectrum of VOCs, like *butylacetate, hexanal, cyclohexanone, ethyl-hexanoic acid, naphtalene*, but also of particulate, formaldehyde, THS (*third-hand smoke*), NBFR, OPFRs and viruses (e.g.; *Norwalk-like viruses, flu-like viruses*)

It must be assessed whether during the construction of the building or in a recent renovation were used insulating foams, glues and resins because, just like paints and coatings, wax and polish could emit VOCs (*propylene glycol, vinyl-cyclohexane, butyl-ether, butilpropionate, methylpropanol, ethylen glycol, propylenglycol, toluene, methyl-pyrrolidinone, phenol, ehtyl-exanoic acid, styrene, naphtalene*), but also O3, formaldehyde, phtalates, NBFR and PCB.

PCBs are a class of organic compounds considered persistent pollutants with toxicity in some cases approaching that of dioxin. Their most common application was as an insulating fluid in transformers, capacitors, and other electric equipment; PCBs were also used as a plasticizer in open systems that included numerous building materials. Volatilization of PCBs from construction materials has been reported to produce PCB levels in indoor air that exceed health protective guideline values, with potential risk to health.

Additive chemicals as flame-retardants (FRs) and plasticizers (as *phthalates*) are typically used in PVC products – flooring, wall covering, and electrical cables – but also in polymers and resins found in a variety of other household and school products as construction materials, furniture and electronics. may pose also a threat to human health; phthalates are currently the most commonly used plasticizers worldwide comprising up to 85% of the total plasticizers in the global market. They are mainly used in PVC plastic consumer products (e.g. wrapping materials, toys, and food containers), personal care products and building materials (e.g. floorings, cables, textiles, wallpapers, paints, glues, etc.). Some phthalates are characterized as endocrine disrupters (EDCs); they may impact affect human health and the reproductive system. Epidemiological studies have found a positive correlation between phthalates in house dust and allergic symptoms or asthma.

Phthalates and FRs are ubiquitous in the school environment because they are not chemically bound to the products in which they are applied; thus, they can be emitted into the surrounding environment and, in particular, accumulate into house dust. Exposure to such chemicals constitutes a particular concern for infants due to their frequent hand-to-mouth behaviour and higher contact with floors

The use of textiles (curtains, carpeting, linoleum) is not common in schools, but can still be, albeit to a lesser extent, a source of pollutants such as VOCs (*acetaldehyde, hexanal, decane, pentanoic acid, acetic acid, hexanoic acid, styrene, acrylonitrile, decane, tetradecane*), formaldehyde, THS and allergens (dust mite).

School supplies

Within the school environment, there are sources of indoor air pollutants represented by everyday objects: school supplies like paper, notebooks and books, electric utilities are a possible source of allergens, viruses, formaldehyde, VOCs (*acetaldehyde, gluteraldehyde*), O3, and UFP.

Markers, crayons or pens have their role: it is necessary to consider that in particular highlighters and permanent markers are possible sources of PAHs, metals (*nickel, arsenic, cobalt, lead*), phthalates, OPFRs (organophosphate flame retardants), azonic dyes

Another important focus should be made on printers, particularly laser printers and copiers, among the main indoor sources of ozone along with air purifiers, but also of acetaldeide, VOCs (*Ethylbenzene, Xylene, 2-ethyl-1-hexanol, Styrene*), O3, particulate, PAHs, formaldehyde, benzene, silicone and metals (3D printers).

In schools that still use it, chalk for blackboards is a source of ultrafine particulate matter; finally, play places and tools can also be sources of airborne pollutants; just think of the possible contamination of surfaces with viruses, or plastic toys (phthalates).

Cleaning products

The use of this kind of products can contribute to the total burden of exposure to several chemicals and constitute a relevant IAQ and health issue. Among the commercially available cleaning agent options, chlorine bleach or sodium hypochlorite is the most commonly used in the developed world. Ammonia-based cleaning agents are very volatile and irritating to the eyes, skin, and mucous membranes. Moreover, heavy exposure to ammonia is associated to respiratory effects such as chronic obstructive bronchitis and bronchial hyperresponsiveness.

Cleaning and disinfectants could release formaldehyde, ammonia and, VOCs (*1,4-dichlorobenzene, butoxyethanol, isopropanol, isopentane, limonene*), as well as personal care products and perfumes (*limonene, siloxane, toluene, ethylbenzene, naphthalene, particulate, benzene and phtalates*).

Emissions from fragranced consumer products can impair indoor air quality and consequently human health, workplace productivity, and quality of life. In particular, air fresheners can emit over 100 different chemicals, including potentially hazardous VOC, (naphthalene, toluene, ethylbenzene, siloxane, limonene), particulate and O3.

Heating systems

The chemistry that enables coal to produce energy - the breaking down of carbon molecules - also produces a number of profoundly harmful environmental impacts and pollutants that harm public health. Air pollution (NO_2, *particulate and UFP, PAHs*, O_3, SO_2 *produced when the sulphur in coal reacts with oxygen),* and global warming are two of the most serious.

Nitrogen dioxide (NO_2) is a product of high-temperature combustion. The principal indoor source of NO_2 is unvented gas appliances (stoves and furnaces). NO_2 may be particularly problematic in the inner city, where gas stoves are common and proper venting rare and using stoves for heating is commonly reported. Indoor levels where NO2 sources, such as gas appliances, were present were much higher than outdoors, where the primary source of NO2 was road traffic.

The main sources of indoor carbon monoxide (CO) are gas appliances, unvented kerosene heaters, and environmental tobacco smoke (ETS). Chamber studies have determined that kerosene heaters are the major source of sulphate aerosols and indoor SO_2; sulphur dioxide is a primary combustion product of fossil fuels, associated with a wide array of adverse health effects, including short-term respiratory morbidity and mortality

Wood smoke from fireplace, stove but also from fires is a mixture of organic carbon and black carbon (BC), secondarily formed organic mass, and a wide range of gaseous species; it’s also a major source of wintertime $PM_{2.5}$ and UFP. Wood smoke includes toxics such as formaldehyde acetaldehyde, and acetonitrile as well as acrolein, polycyclic organic matter (POM), including polycyclic aromatic hydrocarbon (PAH), benzene, and dioxins.

At the world level, almost 3 billion people uses biomass (organic material) fuels as their primary source of domestic energy for cooking, home heating and light, ranging from near zero in industrialised countries to more than 80% in China, India and sub-Saharan Africa.

In Latin America, approximately 50– 75% of households use biomass fuels for cooking, especially in rural areas. Wood is the most frequently used biomass fuel. Biomass combustion engenders PM, CO, NOx, SO2 VOCs; PAHs, heavy metal and greenhouse gases, namely carbon dioxide (CO_2) and methane (CH_4)

Tobacco smoke

Tobacco is the leading cause of preventable death. Tobacco smoke contains more than 4000 chemicals in the form of particles and gases, many of which are known or suspected carcinogens; the most important ones are NO_2, CO_2, CO, particulate, UFP, PAHs but also various VOCs (*acetaldehyde, toluene, xylene, naphthalene*) and metals (*mercury, chromium, cadmium, lead*), formaldehyde, benzene, tar, air nicotine, all of which are major sources of pollution in the indoor environment. The 2001 European Community Respiratory Health Survey reported that 65% of respondents identified at least 1 smoking parent during their childhood, and 39% currently were being exposed to ETS. Particularly, exposures to second-hand tobacco smoke (SHS) in indoor environments have been associated to a wide range of respiratory, cardiovascular, mental and early life ill-health effects. Second-hand tobacco smoking has to be considered as an important ait pollutants indoors, although in principle smoking is not allowed in schools.

Inhaled e-cigarette aerosol is made of compounds with known adverse health effects. Several studies have shown that e-cigarette aerosol contains PM, formaldehyde and other volatile organic compounds (VOCs), such as *toluene, p,m-xylene, as well as tobacco-specific nitrosamines* (TSNAs), *aldehydes*, and metals. Unlike traditional combustible products, e-cigarettes do not generate “side-stream” smoke from the end of a lit cigarette; second-hand exposure from e-cigarettes mainly comes then from the aerosol exhaled by e-cigarette users. Recent studies have found that exhaled e-cigarette aerosol contains nicotine, propylene glycol, glycerol, particulate matter, ultra-fine particles, and VOCs.

THS (third-hand smoke) is a secondary pollutant formed by the reaction of adsorbed nicotine with indoor O3; THS refers to smoke pollutants that remain on surfaces such as clothing, walls, furniture, hair, skin, carpets, and dust after smoking.

SynAir-G

These adhering pollutants can be re-emitted into the gas phase or react with oxidants and other pollutants commonly found in the indoor environment to form secondary pollutants, including carcinogenic compounds. THS has characteristics that can be described by “the four Rs” because it remains as a residue on the smoker’s body and in the places where they have been smoking; reacts with chemicals in the air to generate more toxic chemicals; re-emits, that is, the generation of these toxic chemicals can be re-released into the air; can be resuspended long after smoking has ended to enter the body through inhalation, from hand to mouth, and skin absorption, resulting in a lasting, serious impact on human health. Therefore, it poses a potential health hazard to both smokers and non-smokers.

Many harmful components have been detected in THS, including those specific to tobacco combustion, such as nicotine and TSNAs (*tobacco-specific nitrosamines*), $PM_{2.5}$ as well as VOCs (*acrolein, furans, acrylonitrile, 1,3-butadiene, acetaldehyde, isoprene, toluene, and benzene*). High concentrations of nicotine and TSNAs are found wherever a smoker has been, and as a result of human activity and air circulation, THS is everywhere, and traces can even be found in non-smokers’ homes and non-smoking areas.

Outdoor environment

Indoor pollution may be linked to outdoor air quality, to the point that, in same situations, outdoor air pollution becomes the first component of indoor air pollution. Outdoor pollutants, such as particulate matter (PM), ozone, nitrogen dioxide (NO_2), and volatile organic compounds (VOCs), can infiltrate indoor spaces through open windows, doors, and ventilation systems. The outdoor sources are many:

TRAP: Traffic-related air pollution (TRAP) is a complex mixture of gases and particles resulting from the use of motor vehicles; these pollutants can be emitted directly through the vehicle exhaust as tailpipe emissions and also from non-exhaust sources such as evaporative emissions of fuel, the resuspension of dust, the wear of brakes and tires, and the abrasion of road surfaces, which are collectively referred to as non-tailpipe emissions. TRAP is most important outdoor source of NO2, but also is composed by other gases like CO2, CO, SO2, O3, PM2.5, PM10, and PAHs but also VOCS (*acrolein, toluene, xylene, styrene*).

PM and PAHs represents a serious health threat because they can penetrate into human respiratory system and are known as human carcinogen (group I); epidemiological studies have consistently shown an association between exposure to atmospheric PM, decreased lung function and a higher incidence of respiratory diseases including shortness of breath, asthma, rhinitis, sinusitis, and chronic obstructive pulmonary disease; long term exposure has been associated with the development of lung cancer. Exposure to PM has been also linked with an increased risk of cardiovascular pathologies and worsening of mental health.

Clearly, the presence and percentage of the various components of traffic-related air pollution are highly variable and depend on several factors, including the proximity in our case of the school building to high traffic roads, to traffic lights, the presence of garages and parking lots nearby, the more or less intense use of public transportation and the eventual presence of bus stops.

Industries: Most of the pollution on earth can be attributed to industry, and industrial exhaust is the second-largest source of pollution after automobile exhaust. These industrial exhaust emissions are often accompanied by excessive temperature and heat generation, which subtly changes the climate and causes some cardiovascular and cerebrovascular diseases. These emissions include particulate matter (PM), volatile organic compounds (VOCs), carbon monoxide (CO), ammonia (NH_3), sulfur oxides (SO_x), and carbon dioxide (CO_2).

Landfill: Landfill and waste disposal, but also all kind of garbage, food chunks, polythene bags, cans, animal faeces which are in close proximity of up to 100 m near surrounding can release bioaerosols in the air; anaerobic microbes can also convert organic matter in wastes into gases (*NO2, CO2, SO2*). High concentration of microbes as well as low concentrations of specific microbes in the atmosphere can produce also allergen. The activity of burning the dumps can significantly contribute to air pollution: apart from the emission of greenhouse gases and other particulate matter, burning of waste at landfills could also emit aerosols from primary biological origins, subsequently leading to microbial air pollution.

Desert and soil: The International Panel on Climate Change (IPCC) has estimated that most of the atmospheric particles worldwide are emitted by natural sources, with mineral dust being the second after marine aerosol; the Mediterranean basin is especially vulnerable to injections of desert dust because of its proximity to Sahara to the south and to the Arabian Peninsula to the east. Re-suspended dust and desert dust have been identified among the major constituents of coarse PM.

Construction work: The majority of construction activities are in-situ and organized in the open air. In addition, material transportation, loading and unloading, and stockpiles of earthwork cause large-scale unavoidable emissions. The large particles of these emissions tend to settle down near the construction site after being raised. However, small particles tend to flow with the wind and enter the atmosphere to form suspended solids that are commonly known as construction dust, that has been considered to be an important source of particle pollution. Wind velocity and the superficial dust water content are key factors that affect dust emissions. However, construction dust emission is not only subjected to the influence of climate factors, but also to the monitoring height, construction intensity, and other factors

Agriculture and livestock: Living in livestock dense areas has been associated with health effects in epidemiological studies worldwide. Particularly livestock-related air pollution at the residential level is suggested to be relevant for public health. Adverse health effects reported in relation to livestock farm emissions such as ammonia (NH_3) and particulate matter (PM) include lung function deficits, as well as increased respiratory symptoms like coughing and wheezing. People with chronic obstructive pulmonary disease (COPD) were found to be especially vulnerable to livestock-related NH_3 levels; recently, exposure to livestock farm emitted PM was found to be associated with respiratory health effects, indicating endotoxin as a plausible etiologic agent.

Others: In addition, some outdoor pollutants can react with indoor materials, such as carpets, furniture, and paints, leading to the release of secondary indoor pollutants. For example, outdoor ozone can react with indoor VOCs, leading to the formation of harmful by-products.

In summary, there is a dynamic relationship between outdoor and indoor pollution. Strategies to address indoor air quality often involve a combination of source control, ventilation improvements, and the use of air purification technologies to minimize the impact of outdoor pollutants on the indoor environment.

Role of Ventilation

Ventilation is an essential element for IAQ because it enables elimination of pollutants and therefore has to be considered when studying the impact of air pollution on health outcomes. Poor ventilation rate, air exchanges, and airflow inside schools generate increasing CO2 levels in classrooms that are quite common throughout Europe; low ventilation is correlated to current asthma, mucosal irritation, reduction of concentration ability, dizziness, dry, itchy, or irritated skin on face and hands, dry or irritated throat, dry, irritated, or itchy eyes, headache, pain in neck or shoulders, hoarseness or pain in throat, runny nose and dry, irritated or stuffy nose. So on one hand, ventilation allows to improve indoor air quality: the higher the ventilation rate, the lower the concentration of PM and CO2 but also VOC, bacteria, and moulds detected indoors. On the other hand, it is also through ventilation that any outdoor pollution can enter the building.

Quantifying exposure to sources and related air pollutants

SEM is available on line on the SynAir-G website. It consists of an Excel dataset.

SEM allows to quantify the number of sources to which the schoolchildren are exposed in their class and therefore the number of contaminants: from mono source to several sources and from exposure to a single pollutant to several pollutants (multipollution), eventually in the case of a unique source. Of note, intermediate are possible. The provided Excel dataset is programmed to make such computation.

Discussion

We implemented for the first time a School Exposure Matrix (SEM) allowing to link potential schools' sources exposures with contaminants, allowing researchers to investigate the relationships between school exposures as proxy of the contaminants and health outcomes in schoolchildren, in the absence of objective assessments of the contaminants. Major key utilities of a SEM include epidemiological research, risk assessment, health surveillance, school medicine practice, and research hypothesis generation.

SEM is crucial in epidemiological studies to identify sources exposures and their levels and assess the potential impact on health. Poor indoor air quality resulting from both indoor and outdoor pollution can have adverse health effects. Respiratory issues, allergies, and cardiovascular problems are among the potential health impacts.

Strength and limitations

While SEM offers a valuable tool for estimating environmental exposures in schoolchildren, researchers need to be aware of its limitations and consider the potential impact of exposure misclassification on study results. The use of SEM has to be complemented with more detailed exposure assessments when feasible and appropriate.

SEM is an efficient tool for assessing exposures in large populations, especially in studies where detailed individual exposure data may be challenging or costly to collect. SEM can be useful for historical exposure assessment, allowing researchers to estimate exposures for past periods when detailed exposure data were not systematically collected. SEM facilitate the comparison of exposure levels across different jobs or industries, aiding in identifying patterns and trends in occupational exposures. SEMs provide a standardized approach to exposure assessment, reducing the potential for bias and enhancing comparability across different studies. SEM can be valuable for generating hypotheses about potential associations between school exposures and health outcomes, which can then be further investigated with more detailed exposure assessments.

However, SEM provides average exposure estimates, which may not accurately reflect individual variations in exposure within groups. SEM may not account for changes in practices, technology, or other conditions over time, leading to exposure misclassification, particularly in some countries. SEM may not adequately capture variations in exposure intensity, duration, or frequency, potentially leading to an underestimation or overestimation of true exposure-risk relationships. SEM can introduce exposure misclassification, as individuals within the same school may have different exposure levels, leading to biased risk estimates in epidemiological studies.

Conclusion

Our School Exposure Matrices (SEM) is a tool that can be used in environmental epidemiology to estimate exposures in schoolchildren and other school occupants based on sources. SEM plays a vital role in assessing the risks associated with specific sources. In the long-term, by quantifying exposure levels to various hazards, policymakers can prioritize interventions, establish safety guidelines, and implement preventive measures to reduce environmental risks. This is one of the aims of SynAir-G.

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Perspectives

The checklists and the SEM will be used in the ongoing field surveys conducted in 5 countries (5 schools each). This will provide data on sources and exposure to be published in forthcoming publications.