



World Health
Organization

REGIONAL OFFICE FOR
Europe

Educational course

Chemical pollution of indoor air and its risk for children's health



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

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Abstract

This publication offers an educational course on different aspects of chemical pollution of indoor air and its risk for children's health, including principles of risk assessment and communication aspects. It was created in the context of the WHO project to develop a screening tool for assessment of risks from combined exposure to multiple chemicals in indoor air. The educational material presented here can be used for training and awareness-raising purposes for a wide range of professionals interested in promoting healthy indoor environments for children. These include public health and health-care professionals, medical and nursing students, decision-makers, and non-health specialists working in public settings for children such as kindergartens and schools, including administrative and building managers, teachers, and educators.

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Abbreviations

AAP	American Academy of Pediatrics
ADI	acceptable daily intake
BMD	benchmark dose
BMI	body mass index
BREATHE	Brain Development and School Pollution Ultrafine Particles in School Children
BTEX	benzene, toluene, ethylbenzene and xylene
CAG	chemical assessment group
CDC	United States Centers for Disease Control and Prevention
CICADs	Concise International Chemical Assessment Documents
DLC	dioxin-like chemical
EDC	endocrine-disrupting chemical
ESIS	European Chemical Substances Information System
EU	European Union
FAO	United Nations Food and Agriculture Organization
FEV1	forced expiratory volume in the first second
FVC	forced vital capacity
HESE	Health Effects of School Environment
HI	hazard index
HSDB	Hazardous Substances Data Bank
IARC	International Agency for Research on Cancer
ICSC	International Chemical Safety Cards
IPCS	International Programme on Chemical Safety
IRIS	Integrated Risk Information System
ITER	International Toxicity Estimates for Risk
LOAEL	lowest-observed-adverse-effect level
MOE	margin of exposure
MRI	magnetic resonance imagery
NCD	noncommunicable disease
NO ₂	nitrogen dioxide
NOAEL	no-observed-adverse-effect level
OECD	Organisation for Economic Co-operation and Development
PAH	polycyclic aromatic hydrocarbon
PAHO	Pan American Health Organization
PCA	principal component analysis
PEF	potency equivalency factor

PM	particulate matter
PM ₁₀	particulate matter with a diameter of less than 10 µm
PM _{2.5}	particulate matter with a diameter of less than 2.5 µm
POD	point of departure
PODI	point of departure index
PVC	polyvinyl chloride
QSAR	quantitative structure–activity relationship
RfD	reference dose
RPF	relative potency factor
SAR	structure–activity relationship
SCCS	Scientific Committee on Consumer Safety
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SCHER	Scientific Committee on Health and Environmental Risks
SDG	Sustainable Development Goals
SEaRCH	School Environment and Respiratory Health of Children
SIDS	Screening Information Data Sets
SINPHONIE	Schools Indoor Pollution and Health Observatory in Europe
SOCO	single overarching communication objective
SVOC	semi-volatile organic compound
TEF	toxic equivalency factor
TEQ	toxic equivalent
VOC	volatile organic compound

Introduction

The quality of indoor air is an important health determinant, especially for children. The main sources of hazardous chemicals and particulate matter (PM) in indoor air are emissions from building materials, furniture and consumer products; combustion processes; and the penetration of polluted outdoor air. In studies conducted across the Member States of the WHO European Region, more than 90 chemicals were detected in public settings for children such as schools, day-care centres and kindergartens, most of which can impact children's health. Numerous studies have reported concentrations in indoor air exceeding guidance values. Given that children spend 70–90% of their time indoors and that the likelihood of co-exposure to multiple hazardous pollutants in indoor air is high, the risk for children's health from chemical pollution of indoor air must be addressed.

Measures to reduce and minimize health risks from indoor air pollution are known: they include regulation of ventilation regimes, implementation of good cleaning practices, planning renovations accordingly and avoiding unnecessary chemical-emitting products in rooms. Some of these measures do not require legislative decisions or additional financial resources, and can be taken at all levels, from national to local, and with the involvement of all relevant stakeholders.

Raising awareness among specialists responsible for promoting children's health by sharing knowledge on how to assess, communicate and reduce such risks can support strong action to ensure healthy indoor environments for children. For this purpose, this educational course was developed for public health and health-care professionals, medical and nursing students, decision-makers, and non-health specialists working in public settings for children such as kindergartens and schools, including administrative and building managers, teachers, and educators.

Content and structure of the course

The course provides basic information on indoor air quality as a health determinant with a focus on children's health. It introduces the high-level policy context of creating healthy educational environments for children; indoor and outdoor sources of chemical pollutants and their role in indoor air pollution and other relevant factors influencing indoor air quality; the physiological and behavioural basis of the higher vulnerability of children to chemicals; evidence of the impact of indoor air pollutants on the respiratory, cardiovascular, nervous and immune systems of children of different ages; a methodological approach to assessment of health risks from combined exposure to hazardous chemicals in indoor air; basic principles of risk communication for different stakeholders; and examples of key messages to specific target groups.

The course focuses on chemical pollutants in indoor air. However, in several modules it also addresses PM with a diameter of less than 2.5 μm ($\text{PM}_{2.5}$) and a diameter of less than 10 μm (PM_{10}). While PM is a complex mixture of solid and liquid particles of organic and inorganic substances rather than an individual chemical, it is an important indicator of both indoor and ambient air quality. Given the health relevance of exposure to PM, the course includes information about its main sources and health effects in all modules except for Module 5, which considers only individual chemicals.

The household combustion of solid fuels, which is a major source of indoor air pollution globally and responsible for a high burden of disease mainly in low- and middle-income countries, is outside the scope of this course.

The course is structured in the following six modules and one annex.

- Module 1. Introduction
- Module 2. Sources of pollutants in indoor air
- Module 3. Vulnerability of children
- Module 4. Indoor air pollution and children's health
- Module 5. Health risk assessment
- Module 6. Risk communication
- Annex 1. Examples of key messages to different target groups

The course includes 128 slides in PDF format accompanied by explanatory text. The PowerPoint version is available to interested users upon request. Please email euroceh@who.int for more information.

CHEMICAL POLLUTION OF INDOOR AIR AND ITS RISK FOR CHILDREN'S HEALTH

With a focus on public settings

Educational course

STRUCTURE OF THE COURSE – MODULES

- 1 INTRODUCTION
- 2 SOURCES OF POLLUTANTS IN INDOOR AIR
- 3 VULNERABILITY OF CHILDREN
- 4 INDOOR AIR POLLUTION AND CHILDREN'S HEALTH
- 5 HEALTH RISK ASSESSMENT
- 6 RISK COMMUNICATION

MAIN OBJECTIVES

- Outline the scope of the problem of chemical pollution of indoor air for children's health.
- Share knowledge on the assessment of risks from combined exposure to hazardous chemicals in indoor air.
- Provide basic information on the communication of health risks and the promotion of risk reduction measures.

Module 1

INTRODUCTION



EDUCATION FOR LIFE

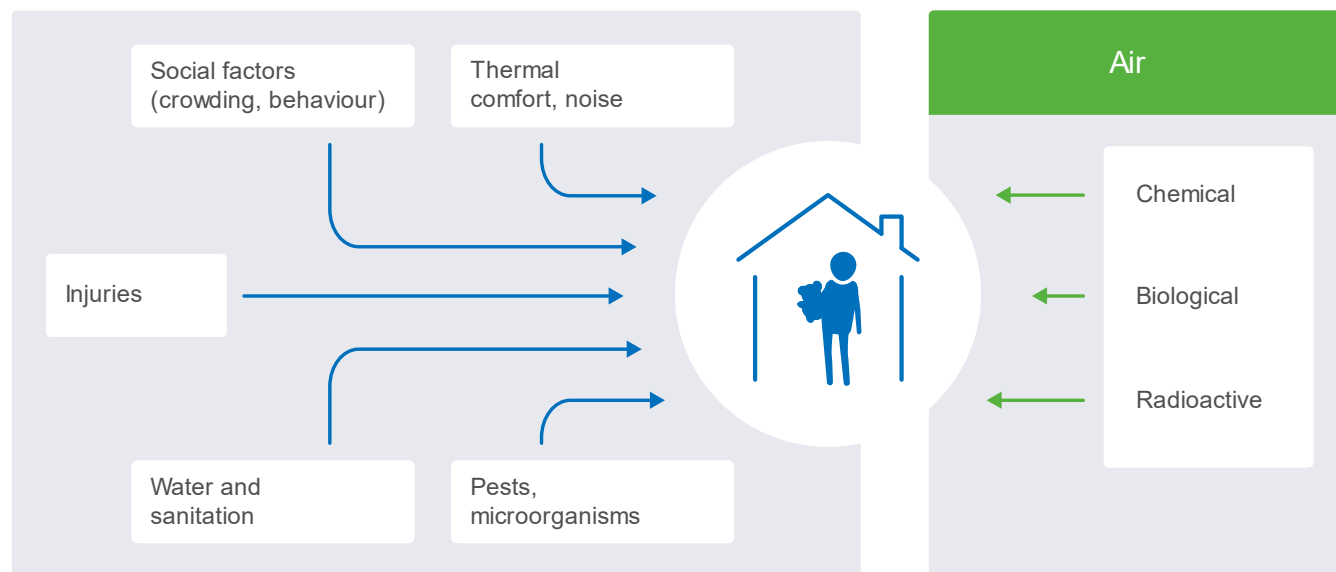
“Healthy environments are crucial for effective learning and development. Healthy, attentive, secure and well nourished children can fully participate in their classes and achieve their full potential. Making sure that these environments are safe and health-promoting is vital.”

(WHO, 2017)

References:

WHO (2017). Inheriting a sustainable world? Atlas on children’s health and the environment. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/254677>, accessed 1 November 2019).

HEALTH DETERMINANTS: THE INDOOR ENVIRONMENT



Children are exposed to many different environments that have a profound influence on their growth and development. Environmental exposures, both adverse and health-promoting, do not work in isolation, but rather interact with social determinants of health. Adverse environmental exposures in early life can have immediate effects or build over time to increase disease risk later in life. In 2015, 26% of the 5.9 million deaths of children under 1 year of age could have been prevented by addressing environmental risks. Hazardous chemicals in food, drinking-water, consumer products, and indoor and outdoor air can pose serious risks to children's health. Given the time that children spend indoors, exposures occurring in built environments are likely to be especially relevant.

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WHO (2017). Inheriting a sustainable world? Atlas on children's health and the environment. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/254677>, accessed 1 November 2019).

WHO Regional Office for Europe (2005). Effects of air pollution on children's health and development. A review of the evidence. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/107652>, accessed 22 July 2020).

AIR QUALITY IS A HEALTH DETERMINANT

Clean air – inside and outside – is a prerequisite for health and well-being.

Despite the introduction of cleaner technologies in the industry, energy production and transport sectors, air pollution remains a serious risk factor.

In the WHO European Region, more than 550 000 deaths were attributable to the joint effects of household and ambient air pollution in 2016. Air pollution was named the fifth-largest risk factor for noncommunicable diseases (NCDs) at the United Nations High-level Meeting on NCDs in September 2018. In 2019 air pollution was considered by WHO as the greatest environmental risk to health.

Clean air outside and inside is one of the main conditions for people's health and well-being. Despite the introduction of cleaner technologies in the industry, energy production and transport sectors, air pollution remains a serious risk factor. The latest data from epidemiological studies indicate that hundreds of thousands of premature deaths in Europe and worldwide are caused by air pollution. Air pollution was named the fifth-largest risk factor for noncommunicable diseases (NCDs) at the United Nations High-level Meeting on NCDs in September 2018. In 2019, air pollution was considered by WHO as the greatest environmental risk to health.

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WHO (2020). Ten threats to global health in 2019 [website]. Geneva: World Health Organization (<https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019>).

A HEALTHY ENVIRONMENT IS EVERY CHILD'S RIGHT

The Convention on the Rights of the Child (Article 24)

States Parties have heightened their obligations to respect, protect and fulfil the rights of children. These obligations include:

- ensuring that educational programmes increase children's understanding of environmental issues and strengthen their capacity to respond to environmental challenges;
- assessing the effects of proposed measures on children's rights before the measures are taken or approved;
- collecting information on sources of environmental harm to children and making the information publicly available and accessible;
- facilitating the participation of children in environmental decision-making and protecting them from reprisals for their participation or otherwise expressing their views on environmental matters; and
- removing barriers to children's access to justice for environmental harm so that they can fully enjoy their rights.

A healthy environment is essential for children to fully enjoy their right to health. The Convention on the Rights of the Child – a universally ratified human rights treaty – requires States Parties to pursue full implementation of children's right to health by appropriate measures that include the provision of nutritious foods and clean drinking-water, and that take into consideration the dangers and risks of environmental pollution (Article 24 (2.c)).

Air pollution in particular jeopardizes children's right to health. Countless children suffer from disease and disability related to air pollution, and because these can disrupt their physical and cognitive development, they often have lifelong effects.

References:

United Nations (1989). Convention on the Rights of the Child. United Nations Treaty Series, Vol. 1577. New York: United Nations (<http://www.refworld.org/docid/3ae6b38f0.html>, accessed 1 November 2019).

NONTOXIC ENVIRONMENTS FOR A SUSTAINABLE FUTURE FOR CHILDREN



Sustainable Development
Goal (SDG) target 3.9:

By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.



SDG target 4.a:

Build and upgrade education facilities that are child, disability and gender sensitive, and provide safe, nonviolent, inclusive and effective learning environments for all.

The beginning of the Sustainable Development Goal (SDG) era is a great global opportunity to put renewed focus on children's environmental health. Several SDGs address sound chemical management (SDGs 3, 6 and 12) and air pollution (SDGs 7, 11 and 13). Reducing indoor air pollution is particularly critical for the achievement of SDG target 3.9 – to substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination by 2030.

SDG 4 – to ensure inclusive, equitable, quality education and to promote lifelong learning opportunities for all – specifically calls for building and upgrading education facilities that are child, disability and gender sensitive, and that provide safe, nonviolent, inclusive and effective learning environments for all.

References:

United Nations (2015). Transforming our world: the 2030 Agenda for Sustainable Development. New York: United Nations (https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E, accessed 1 November 2019).

INDOOR AIR QUALITY – AN ENVIRONMENTAL HEALTH AGENDA PRIORITY

- Improving indoor and outdoor air quality for all
- Minimizing the adverse effects of chemicals on human health and the environment

I. We will **develop appropriate cross-sectoral policies and regulations** capable of making a strategic difference **in order to reduce indoor pollution**, and we will provide incentives and opportunities to ensure that citizens have access to sustainable, clean and healthy energy solutions in homes and public places.

II. We aim to **provide each child with a healthy indoor environment in child care facilities, kindergartens, schools and public recreational settings**, implementing WHO's indoor air quality guidelines and, as guided by the Framework Convention on Tobacco Control.



Ministerial conferences on environment and health; Parma and Ostrava declarations on environment and health.



The 2010 Parma Declaration on Environment and Health and the 2017 Ostrava Declaration on Environment and Health outlined policy frameworks for action towards clean indoor and outdoor air. Reducing indoor pollution and providing each child with healthy indoor environments in child-care facilities, kindergartens, schools and public recreational settings are the main commitments of ministries of health and the environment.

The Sixth Ministerial Conference on Environment and Health in Ostrava, Czechia, affirmed countries' commitment to reducing indoor air pollution caused by, inter alia, cooking, heating, tobacco smoke, inadequate ventilation and chemicals.

References:

WHO Regional Office for Europe (2010). Parma Declaration on Environment and Health. Fifth Ministerial Conference on Environment and Health. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0011/78608/E93618.pdf, accessed 1 November 2019).

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WHO Regional Office for Europe (2017). Compendium of possible actions to advance the implementation of the Ostrava Declaration. Sixth Ministerial Conference on Environment and Health. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0008/341945/Annex1_13June.pdf?ua=1, accessed 1 November 2019).

THE ROLE OF HEALTH PROFESSIONALS IS ...



... to be informed and to research, publish and disseminate knowledge.



... to educate colleagues, students, families and communities.



... to recognize exposures and related health conditions.



... to raise awareness and advocate for risk-reduction solutions to policy- and decision-makers.

All health professionals should consider air pollution – both indoor and outdoor – as a major risk factor for health of their patients, and should be informed on the relevant sources of environmental exposure in the communities they serve. Health-care and public-health professionals can play a pivotal role in properly communicating the risks of indoor air pollution and in advocating for the implementation of risk-reduction measures. They should:

- be informed about existing and emerging evidence on air pollution and related children's health detriments;
- identify causative risk factors for managing disease and prevent exacerbations;
- conduct and publish evidence from their practice on the underlying mechanisms of the health effects of children's environmental exposure, on potential treatment and its effectiveness, and on strategies for disease prevention and management;
- raise awareness, educate families and communities, provide options for solutions, inform about social and behaviour changes leading to better indoor air quality;
- train others in the health and education fields to increase the reach of their messages on the health risks of air pollution, and disseminate evidence-based strategies to reduce exposure;
- support the inclusion of children's environmental health in curricula in post-secondary institutions and particularly in medical, nursing and midwifery schools; and
- share knowledge with decision-makers, support improved standards and policies to reduce harmful exposure, advocate for monitoring and emphasize the need to protect children at risk.

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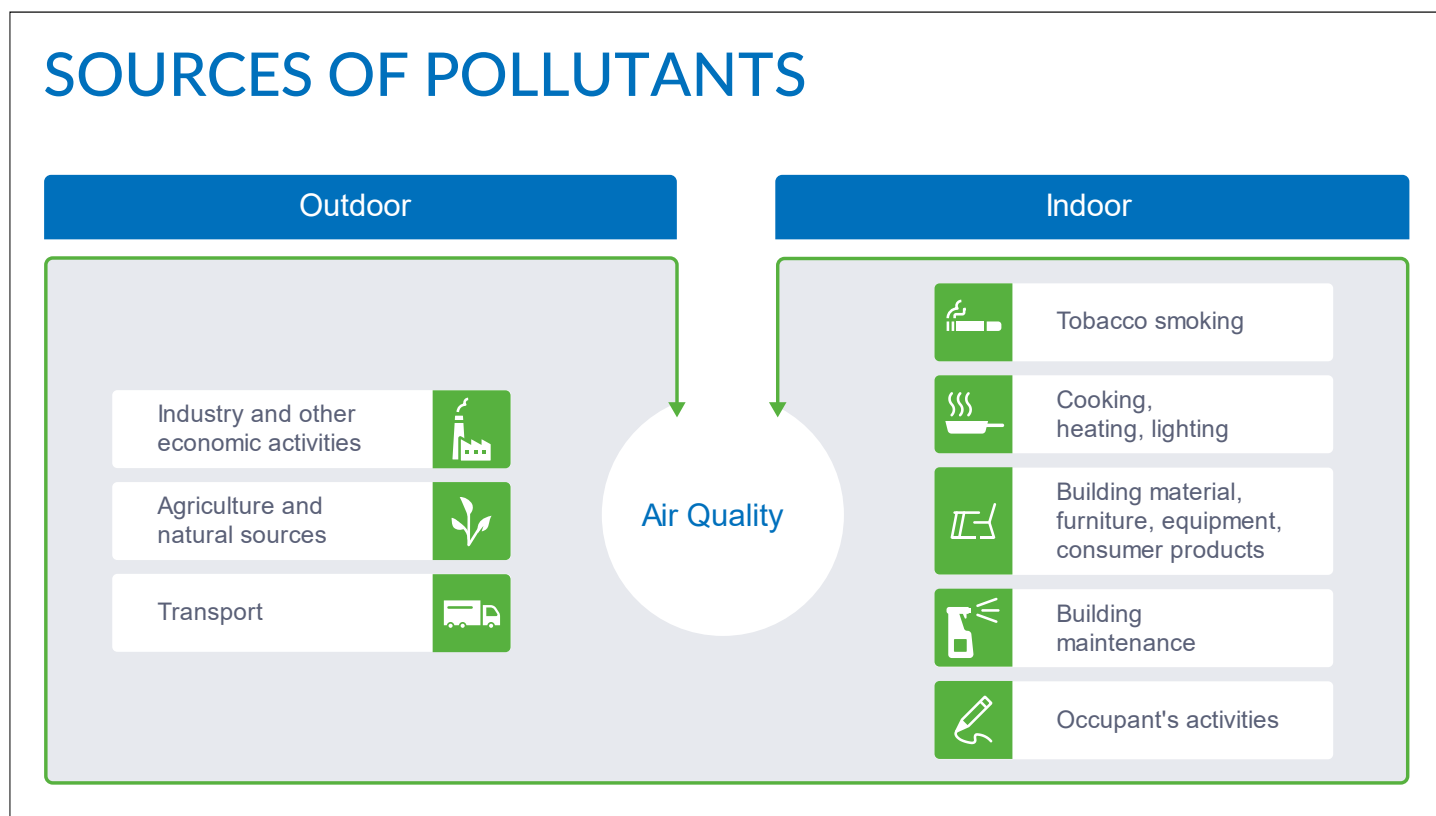
SUMMARY OF MODULE 1

- Air quality (indoors and outdoors) is a health determinant.
- Actions aimed at improving air quality contribute to achieving the SDGs and to the well-being of children.
- The Convention on the Rights of the Child obliges States Parties to respect, protect and fulfil the right of children to a healthy environment.
- Working for improving indoor and outdoor air is a high-level commitment in WHO European Region.
- Health professionals play a critical role in reducing children's exposure to air pollution.

Module 2

SOURCES OF POLLUTANTS IN INDOOR AIR

SOURCES OF POLLUTANTS



Indoor air quality is affected by many factors. Studies have revealed that outdoor environments are a major source of chemical pollution in indoor environments. In urban areas, air pollutants are mainly emitted from motorized transport, but power plants, industry and incinerators. Some other economic activities (for example, construction works) also contribute, depending on their locations and the prevailing winds. Agricultural activities in rural areas and the use of pesticides can contribute to the contamination of indoor air in nearby buildings.

According to WHO, around 3 billion people in the world still cook and heat their homes using solid fuels such as waste wood, charcoal, coal, dung and crop wastes. This generates a large amount of air pollutants, including sulfur dioxide, nitrogen oxides, carbon monoxide, PM, and carcinogenic compounds. In the WHO European Region, the percentage of population using solid fuels for cooking and heating varies from 5% to 50% in different countries.

The main indoor sources of chemical pollutants are building materials and construction products, furniture, tobacco smoking, and the use of household cleaning products and other products (for example, air fresheners). Occupants also release certain chemicals into indoor environments through their metabolic processes, use of personal care products and activities conducted indoors. The use of paints, glues and other products for didactic purposes are among the important sources of indoor pollution in school buildings.

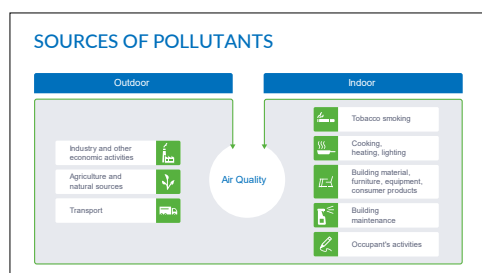
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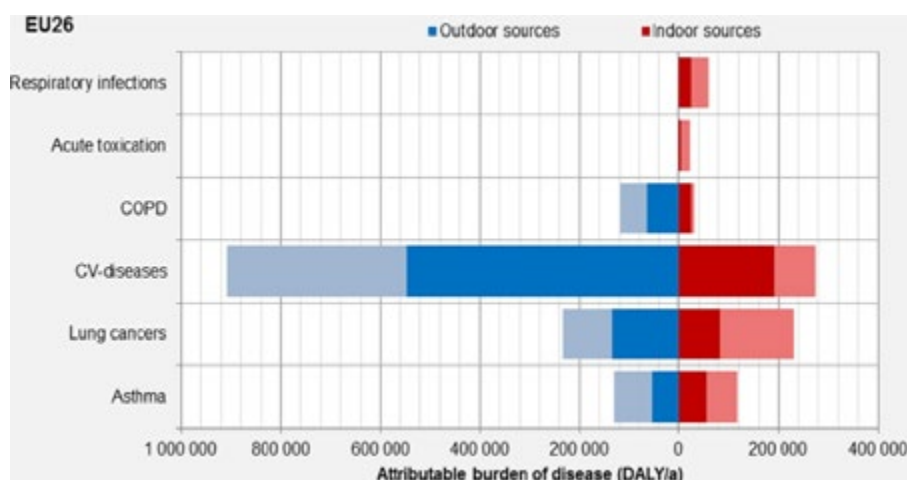
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ATTRIBUTABLE BURDEN OF DISEASES DUE TO INDOOR EXPOSURES IN 2010 IN 26 COUNTRIES OF THE EUROPEAN UNION (EU26)



The lighter shades of blue and red represent the proportion of the current burden of disease that could be avoided through control policies for residential indoor exposures to particulate matter (PM) with a diameter of less than $2.5 \mu\text{m}$ ($\text{PM}_{2.5}$), outdoor bioaerosols, volatile organic compounds (VOC), carbon oxide, radon and dampness.

(Reproduced without changes from Asikainen, A., Carrer, P., Kephelopoulou, S. et al. Reducing burden of disease from residential indoor air exposures in Europe (HEALTHVENT project). *Environ Health* 15, S35 (2016). HYPERLINK "<https://doi.org/10.1186/s12940-016-0101-8>" doi:10.1186/s12940-016-0101-8. License: HYPERLINK "<https://creativecommons.org/licenses/by/4.0/>" CC BY 4.0)

*COPD: chronic obstructive pulmonary disease; CV: cardiovascular; DALY/a: disability-adjusted life-year per year

The potential contribution of outdoor air pollutants to the burden of disease attributable to indoor air pollution (DALY) was calculated in the framework of the European Union project "Promoting actions for healthy indoor air" (IAIAQ) in 2011. According to the estimates, pollutants originating from outdoor sources are responsible for some two thirds of the total burden of disease from exposures to indoor air. The figure presents the burden of disease associated with indoor air quality in 26 countries of the European Union (EU26), differentiating the contribution from outdoor and indoor sources (the latter includes radon). It also demonstrates that the impacts of indoor air quality on public health are huge.

* DALY - One DALY can be thought of as one lost year of "healthy" life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability (WHO, 2020).

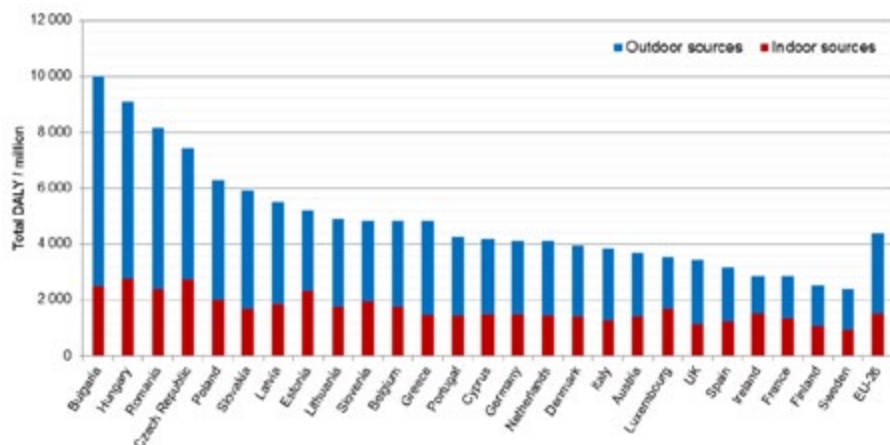
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TOTAL BURDEN OF DISEASES AS DALY PER MILLION POPULATION FROM INDOOR EXPOSURES IN THE EU26



The image shows the total burden of disease as DALY/million population from indoor exposures in EU-26 countries with the division of indoor and outdoor sources in the 2010 building stock.

Scenario of exposure to: PM_{2.5}, bioaerosols, VOCs, carbon monoxide, radon and dampness.

(Reproduced without changes from Asikainen, A., Carrer, P., Kephelopoulos, S. et al. Reducing burden of disease from residential indoor air exposures in Europe (HEALTHVENT project). *Environ Health* 15, S35 (2016). HYPERLINK "<https://doi.org/10.1186/s12940-016-0101-8>" doi:10.1186/s12940-016-0101-8. License: HYPERLINK "<https://creativecommons.org/licenses/by/4.0/>" CC BY 4.0)

This slide illustrates the potential contribution of outdoor air pollutants to the burden of disease attributable to indoor air pollution in the EU26.

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SOURCES OF INDOOR AIR POLLUTANTS: OUTDOOR SOURCES



Motorized transport

- Busy roads
- Parking (parking spaces and idling)



Industrial sites

- Power plants
- Gasoline stations
- Small workshops
- Waste dumping sites and landfills



Agriculture

- Use of pesticides and agrochemicals
- Manure/fertilizers



Other sources

- Loading/unloading places (for example, supermarkets)
- Construction works
- Rubbish bins
- Ventilation exhaust from other buildings

Distance and wind direction are important factors.

The most important and common outdoor sources of air pollutants are motorized transport, the energy production sector, commercial and institutional buildings and homes, industry, construction, agriculture, and waste management. The main outdoor pollutants, including nitrogen oxides, sulfur dioxide, ozone, carbon monoxide, hydrocarbons and PM of different sizes, can penetrate building envelopes, namely through windows and ventilation systems. Due to differences in the number, density and characteristics of sources (for example, type of building material), and effectiveness of emission control technologies (if they exist), the relative contribution of these sources to indoor air pollution varies considerably.

Spatial gradients also vary significantly according to the characteristics of the pollutant(s) produced. In fact, distance from the pollution source and wind direction both play a pivotal role in the level of outdoor pollutants found indoors. In the first 50–100 metres from major roads, steep, nonlinear decreases in concentrations of pollutants were observed. Smaller decreases were observed 300–500 metres from the roads. Air pollution from motorized transport can affect indoor air quality at distances ranging from 15 metres up to 375 metres when the wind is blowing directly from the road.

Plumes from power plants and fires, even when diluted, can still be identified at a distance of tens to thousands of kilometres. Secondary pollutants*, for example, ozone, sulfate and some volatile organic compounds (VOCs), are found regionally with relatively smaller gradients.

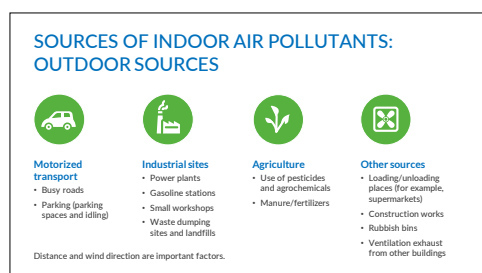
* An example of a secondary pollutant is not directly emitted as such, but forms when other pollutants (primary pollutants) react in the atmosphere. Example of a secondary pollutant include ozone, which is formed when hydrocarbons and nitrogen oxides combine in the presence of sunlight.

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SOURCES OF INDOOR AIR POLLUTANTS: INDOOR SOURCES (I)



Building materials

- Coatings
- Flooring
- Doors
- Windows



Equipment

- Computers
- Printers
- Interactive blackboards



Furnishings

- Furniture
- Sun screens/
curtains



Other

- Kitchens/canteens
- Laboratories
- Consumer products

Time after renovation/installation is important.

There are many sources of hazardous pollutants inside buildings, including building materials, furniture, equipment, consumer products, laboratory chemicals and chemicals used for building maintenance (for example, cleaning products). The level of chemicals released strongly associates with time after the introduction of the source(s) indoors (for example, from date of renovation or installation of new furniture).

For example, classroom wall renewal was associated with increased levels of benzene, toluene, ethylbenzene and xylene (BTEX) for one year. In one study, formaldehyde levels were the same as in classrooms that were not renovated, but VOC levels were higher immediately after completion of construction. Toluene levels were also above the guideline value, and the emission from three types of polyvinyl chloride (PVC), linoleum, rubber and the four different type of adhesives were high in the first days after installation. After 10 and 28 days, the emission rate was decreasing, but emission rates from some PVC materials were still high.

All factors influencing indoor air quality should therefore be considered when planning risk-reduction measures.

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SOURCES OF INDOOR AIR POLLUTANTS: INDOOR SOURCES (II)



Tobacco smoke



Maintenance of buildings

- Cleaning products
- Air fresheners, etc.



People

- Crowded places
- Activities (painting, laboratory work, etc.)



Use of insecticides, disinfectants

Indoor smoking contributes to a significant increase in indoor concentrations of carbon monoxide, VOCs and PM. Environmental tobacco smoke is by far the dominant parameter influencing indoor PM and BTEX (comprising benzene, toluene, ethylbenzene and xylene) concentrations, far beyond the contribution of nearby traffic sources. A study on characterizing levels of indoor PM with a diameter of less than 10 μm (PM_{10}) showed that the physical activity of pupils and class work greatly contributed to the emission and/or resuspension of particles, which were found to be consistently at higher amount indoors than outdoors, except in non-occupied periods.

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THE INDOOR–OUTDOOR RELATIONSHIP

The level of exposure from pollutants in indoor air is commonly higher than in outdoor air.

- A wider range of pollutants is reported in indoor air.
- People spend more time indoors than outdoors.
- Concentrations of certain pollutants are higher indoors than outdoors.

Outdoor air

Higher concentrations of: black carbon, nitrogen dioxide (NO₂) and PM_{2.5}

Indoor air

Higher concentrations of: formaldehyde, VOCs and PM with a diameter of less than 10 μm (PM₁₀)

The majority of existing studies report higher levels of certain pollutants inside schools and kindergartens than outside. This has been demonstrated for aldehydes (mainly for formaldehyde, but also for acetaldehyde, propionaldehyde and benzaldehyde), as well as for PM₁₀ and all VOCs except benzene. The concentration of black carbon, nitrogen dioxide (NO₂) and PM with a diameter of less than 2.5 μm (PM_{2.5}) were generally higher outdoors.

As a rule, concentrations of many indoor pollutants are higher in households due to tobacco smoking, heating and cooking practices, other domestic activities and use of specific consumer products. According to WHO observations, indoor exposures to formaldehyde are the dominant contributor to personal exposures through inhalation and outdoor air does not contribute to indoor pollution (or the contribution is minor). NO₂ and ozone levels were higher outdoors than indoors in SINPHONIE project. However, PM_{2.5} found in the SINPHONIE classrooms resulted mostly from indoor rather than outdoor sources, as shown by the indoor/outdoor ratio of 1.4. All the other air pollutants were emitted mostly from indoor sources.

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THE INDOOR–OUTDOOR RELATIONSHIP

The level of exposure from pollutants in indoor air is commonly higher than in outdoor air.

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- People spend more time indoors than outdoors.
- Concentrations of certain pollutants are higher indoors than outdoors.

<p>Outdoor air</p> <p>Higher concentrations of: black carbon, nitrogen dioxide (NO₂) and PM_{2.5}</p>
<p>Indoor air</p> <p>Higher concentrations of: formaldehyde, VOCs and PM with a diameter of less than 10 µm (PM₁₀)</p>

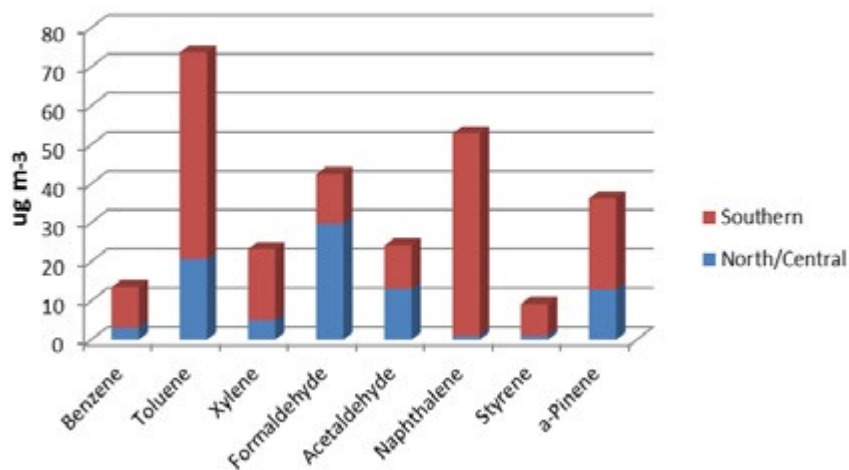
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INDOOR AIR POLLUTION: GEOGRAPHIC DIFFERENCES



The chart shows concentrations of major organic compounds in residential settings in Europe.

(WHO Regional Office for Europe, 2014)

The contamination of indoor air can be also dependent on countries' locations and climates and other related factors to that (heating, airing, energy-saving construction of buildings, etc.) and the conditions of different seasons.

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INDOOR AIR POLLUTION: OTHER DETERMINING FACTORS



- Location (urban vs rural)



- Ventilation rate



- Microenvironment conditions temperature and humidity

The major outdoor sources of hazardous pollutants such as vehicles, power generation, building heating systems, waste incineration and industry are located in urban areas. These sources determine differences in levels of outdoor air pollution between rural and urban areas, with expected higher pollution in highly industrialized cities. However, use of solid fuel for heating, which is more common for rural areas, plays an important role in indoor air pollution and can be a cause of higher air pollution in rural areas during heating seasons. Natural and mechanical ventilation are essential for controlling indoor air quality: the correlation between ventilation conditions and indoor air quality were reported in many studies. These correlations may vary according to the location of the main source of each pollutant (outdoor vs indoor) and when indoor, whether the source is associated with occupant activity or continuous emission.

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SOURCES OF POLLUTANTS IN INDOOR AIR (I)

Chemical	Source of chemical	
PM (PM _{2.5} and PM ₁₀)	Outdoor sources (classical outdoor air pollutants)	Industrial emissions, motor vehicle exhaust, emissions from energy industries (coal, wood, etc.), fires
NO ₂		Motor vehicle exhaust
Ozone		Motor vehicle exhaust
Carbon monoxide		Incomplete combustion of wood, petrol, coal, natural gas and kerosene; parking areas
Formaldehyde	Outdoor sources (other air pollutants)	Production and use in industry, motor vehicle exhaust, power plants, waste incineration
Naphthalene		Production and use in industry, motor vehicle exhaust
Benzene		Motor vehicle exhaust, petrol stations, chemical and steel industries, industrial sites where coal, oil or natural gas are burned
Polycyclic aromatic hydrocarbons (PAHs)		Motor vehicle exhaust, industry, power production, waste incineration

PM is emitted mainly by heating, industry and transport; nitrogen oxides are mainly released by transport; the bulk of sulfur oxides come from energy production and off-road transport; almost all ammonia emissions come from agriculture; VOCs are mainly emitted from the use of solvents and products (paints and chemicals used in manufacturing and maintenance); carbon monoxide emissions come from heating and transport.

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accessed 1 November 2019).

SOURCES OF POLLUTANTS IN INDOOR AIR (II)

Chemical	Source of chemical	
Benzene	Indoor sources	Building and decorative materials, furniture, heaters, various human activities, cleaning products, consumer products, office equipment (laser printers, photocopiers), environmental tobacco smoke
Formaldehyde		Wood materials (used as a chemical preservative, disinfectant, biocide, and component of varnishes and adhesives), fabric, printed materials, combustion processes, environmental tobacco smoke, air fresheners, secondary chemical processes in indoor air (VOC oxidation, reaction between ozone and alkenes)
Naphthalene		Consumer products (solvents, lubricants, hair sprays, air fresheners), heaters (mostly kerosene), environmental tobacco smoke, rubber materials, repellents
NO ₂		Environmental tobacco smoke, appliances that burn gas, wood, oil, kerosene or coal
PAHs		Environmental tobacco smoke, appliances that burn solid fuel

Below is a list of common chemicals in indoor air and examples of their potential indoor sources.

- Sulfur dioxide – vulcanized rubber, tobacco smoking, burning of gas, wood, oil, kerosene and coal
- Nitrogen oxides – dry-process photocopiers, tobacco smoking, burning of gas, wood, oil, kerosene and coal
- Sulfur compounds such as hydrogen sulfide, carbonyl sulfide and carbon disulfide – flooring materials and wool carpets
- Acetaldehyde – wooden-pressed products, wall and floor coverings and paints, human activities, artists' linseed oil paints, other drying oils, terracotta bricks, ceramic manufacturing, kilns, vinyl, laminates, wallpapers, acrylic melamine coatings, alkyd paints, latex and low-VOC latex paints
- Formaldehyde – adhesive and sealants, coating products, furniture and wood products, medium-density fibreboard, laminate flooring, linoleum, cork, acrylic and water based paints, insulating materials, textile, modelling clay, ink and toners, polishers and waxes, washing & cleaning products and personal care products, plywood and clipboards, artists' linseed oil paints, other drying oils, terracotta bricks, ceramic manufacturing, kilns, vinyl, laminates, wallpapers, acrylic melamine coatings, alkyd paints, latex and low-VOC latex paints
- Benzene – smoking, solvents, carpet glue, possible re-emission by laminate flooring, acrylic and water-based paints
- Naphthalene – smoking, insecticides and repellents
- Styrene – building products, smoking, rubber and epoxy adhesives
- Toluene – polishes, paints, adhesives,
- Xylenes – plaster, paints, particle board, various adhesives

References:

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continued

SOURCES OF POLLUTANTS IN INDOOR AIR (II)

Chemical	Source of chemical
Benzene	Building and decorative materials, furniture, heaters, various human activities, cleaning products, consumer products, office equipment (laser printers, photocopiers), environmental tobacco smoke
Formaldehyde	Wood materials used as a chemical preservative, disinfectant, biocide, and component of varnishes and adhesives; fabric, printed materials, combustion processes, environmental tobacco smoke, air fresheners, secondary chemical processes (in indoor air (VOC oxidation, reaction between ozone and alkenes))
Naphthalene	Consumer products (solvents, lubricants, hair sprays, air fresheners), heaters (mostly kerosene), environmental tobacco smoke, rubber materials, repellents
NO _x	Environmental tobacco smoke, appliances that burn gas, wood, oil, kerosene or coal
PAHs	Environmental tobacco smoke, appliances that burn solid fuel

Kaiser A, Hannu H (2013). Emissions from different floor materials and adhesives in indoor air. Conference paper. Chennai: International Conference on Advances in Building Sciences. doi:10.13140/RG.2.2.21267.27685.

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SOURCES OF POLLUTANTS IN INDOOR AIR (III)

Chemical	Source of chemical	
Carbon monoxide	Indoor sources	Appliances that burn fossil fuels and biomass, environmental tobacco smoke
Limonene		Flavored/fragranced additives in household products, cleaning products
Trichloroethylene		Colorful paint (wood stains, varnishes, lubricants, adhesives)
Tetrachloroethylene		Consumer products (glues, air fresheners, stain removers, wood cleaners)
Ozone		Office equipment (computers, laser printers, photocopiers)

Below is a list of common chemicals in indoor air and examples of their potential indoor sources.

- Ozone – office/building equipment, including dry-process photocopiers
- Secondary pollutants – resultant from indoor chemistry (for example, oxidant pollutant-mediated reactions, as ozone-terpene reactions and carpet-ozone interactions)
- α -Pinene and limonene – cleaning products, wood-based products, air fresheners, biocides

References:

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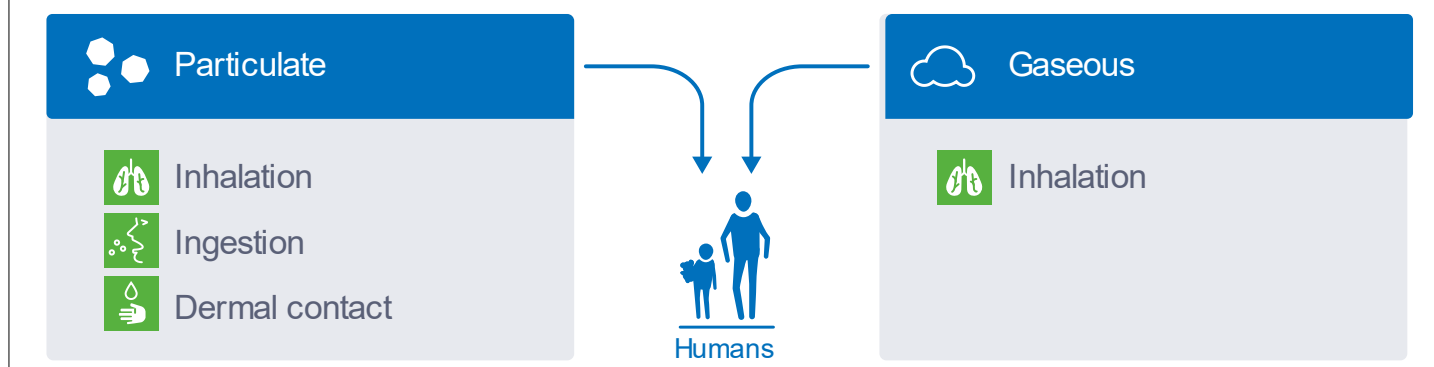
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GASEOUS AND PARTICULATE FORMS

Pollutants in indoor air exist in two main phases: gaseous and particulate. Pathways of exposure depend on the phase.

- Particulate form includes PM_{10} , $PM_{2.5}$, ultrafine particles, black carbon, phthalates and semivolatile organic compounds (SVOCs).
- Gaseous form includes VOCs, nitrogen oxides, carbon oxides, sulfur dioxide and ozone.



Pollutants in indoor air exist in two main phases: gaseous and particulate. Pollutants in gaseous form that are hazardous to human health include nitrogen oxides, sulfur dioxide, carbon oxides, ozone and VOCs. Chemicals in particulate form include phthalates, semivolatile organic compounds (SVOCs) and some polycyclic aromatic hydrocarbons (PAHs), which can be present both in the air and in sediment (dust). PM, such as PM_{10} , $PM_{2.5}$, ultrafine particles and black carbon, differ according to their size, shape and composition.

Pathways of exposure to a given pollutant differ according to the respective phase(s): inhalation is the major pathway of exposure to gaseous forms of pollutants. Dermal contact is also possible. Inhalation, dermal contact and, in some conditions, ingestion (for example, potentiated in children due to the common hand-to-mouth behaviour) are the possible pathways of exposure to particulate forms.

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SUMMARY OF MODULE 2

- There are many sources of pollutants in indoor air.
- Both outdoor and indoor sources contribute to indoor air pollution.
- Pollutants in indoor air can present in gaseous and particulate forms that determine pathways of exposure.
- The most common pollutants are classical outdoor pollutants such as PM, nitrogen oxides, carbon oxides, sulfur dioxide, ozone and other pollutants of outdoor and indoor origin (for example, formaldehyde, benzene, xylenes, styrene, toluene).
- The concentration of some pollutants (for example, formaldehyde) is commonly higher indoors than outdoors. Thus, there is a higher health risk posed by indoor air pollution.

Module 3

VULNERABILITY OF CHILDREN



CHILDREN ARE NOT JUST SMALL ADULTS: CHARACTERISTICS OF CHILDREN



Children are at greater risk than adults to many adverse effects resulting from exposure to hazardous chemical pollutants. This increased vulnerability results from a combination of physiological, biochemical, behavioural, and social characteristics. This susceptibility is particularly critical at early stages of development when organs and systems are still maturing. In fact, children have a larger lung surface area per kilogram of body weight than adults, breathe faster than adults and present a hand-to-mouth behaviour, characteristics that significantly potentiate the intake of hazardous pollutants.

Following inhalation exposure to the same concentrations of pollutants, the peak blood concentrations of highly metabolized chemicals (for example, furan) in children in the age groups 6, 10, and 14 years have been found to be greater than those recorded for adults by a factor of 1.5 using a physiological modelling approach. In the case of such highly extracted chemicals, the blood concentration is determined by age-dependent tissue volumes, blood flow rates, breathing rate, and cardiac output. In addition, children have very active behaviour that leads to the resuspension of dust and increases breath rate and exposure.

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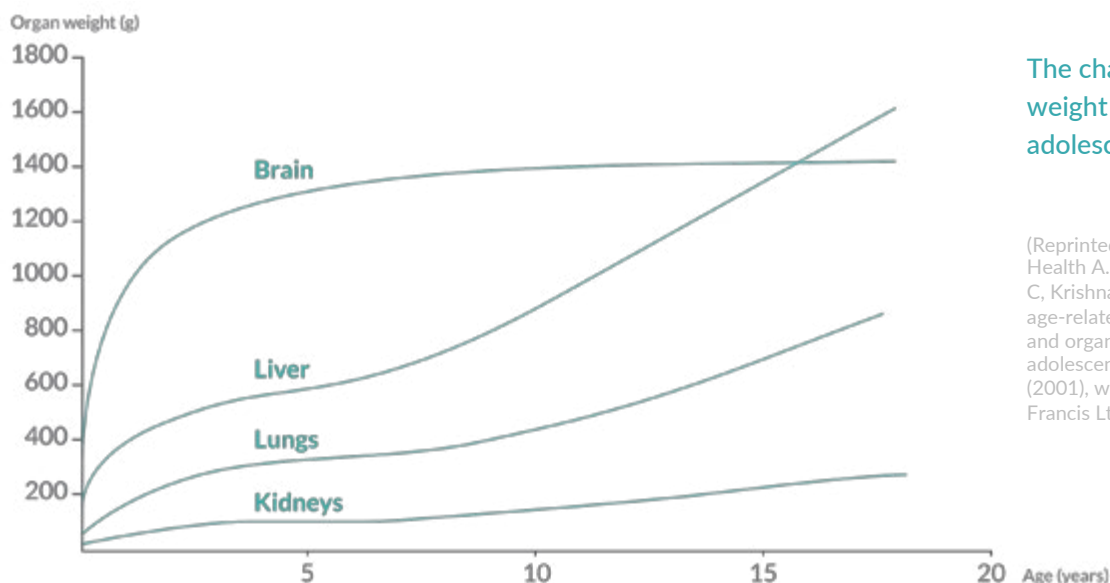
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DEVELOPMENT OF ORGANS AND SYSTEMS IN CHILDREN



The chart shows organ weight from birth to adolescence in boys.

(Reprinted from: J. Toxicol Environ Health A. Vol 64(6). Haddad S, Restieri C, Krishnan K. Characterization of age-related changes in body weight and organ weights from birth to adolescence in humans. 453-64 (2001), with permission from Taylor & Francis Ltd)

The health effects of chemicals depend on their hazardous properties, but also on how chemicals are decontaminated through biochemical reactions in organisms and how they are eliminated – that is, on toxicokinetics. The toxicokinetics and tissue dose of chemicals may differ between adults and children. Children's organs grow as they do. Data on human body weight and organ weights as a function of age (specifically between birth and 18 years of age) are summarized in the image.

The specific organs/tissues/fluids for which data on age-related weight are available include blood, adipose tissues, liver, lungs, brain, heart, kidneys, spleen, reproductive organs (male: prostate gland, seminal vesicle, testes and epididymis; female: ovaries, uterus and uterine tubes), glands (adrenal, pituitary, thymus, pancreas and thyroid), bone marrow (total and red), intestinal tract, stomach, muscle, skin (epidermis and dermis) and skeleton. In both male and female children, the sum of these organs is systematically lower than the body weight and lower than in adults. This can influence chemicals' effects on children in comparison with adults.

References:

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DEVELOPMENT OF THE RESPIRATORY SYSTEM IN CHILDREN

Stage	Infant to 1 year	Young child 1–4 years	Older child 5–12 years	Adoles- cent 12–18 years
Alveolar development	[Dark Blue]			[Light Blue]
Lung volume	[Dark Blue]			
Lung growth	[Dark Blue]			

In children, particles are moved through the respiratory system faster, allowing them to reach the lungs, the alveoli and the bloodstream rapidly.

- The lungs are growing throughout childhood and adolescence.
- Postnatal growth and maturation are driven by the processes of branching morphogenesis and alveolarization.
- The breathing rate of children is twice as high as that of adults; thus children inhale larger amounts of pollutants.
- The ventilation rate of children is greater because they are physically more active.
- Larger lung surface area per kilogram of body weight can facilitate the absorption of chemicals.
- Narrower airway passages lead to irritation and inflammation from exposures that can result in a proportionally greater obstruction.
- Exposure to air pollutants can exacerbate existing health conditions and cause additional complications.

Children's respiratory systems continue developing after birth. Lung growth continues until about 20 years of age. Children breathe more rapidly than adults because of their higher resting metabolic rate, and as a consequence they inhale more air – and more air pollutants – relative to their body weight. They also have a larger lung surface area per kilogram of body weight than adults. During early life, the respiratory system grows and develops rapidly through the processes of branching morphogenesis; a higher ratio of lung surface area to volume facilitates the absorption of chemicals. Finally, children's airway passages are narrower than those of adults. Thus, any irritation and subsequent inflammation from exposure to air pollutants can result in proportionately greater airway obstruction. Children with respiratory or cardiovascular conditions are at particular risk.

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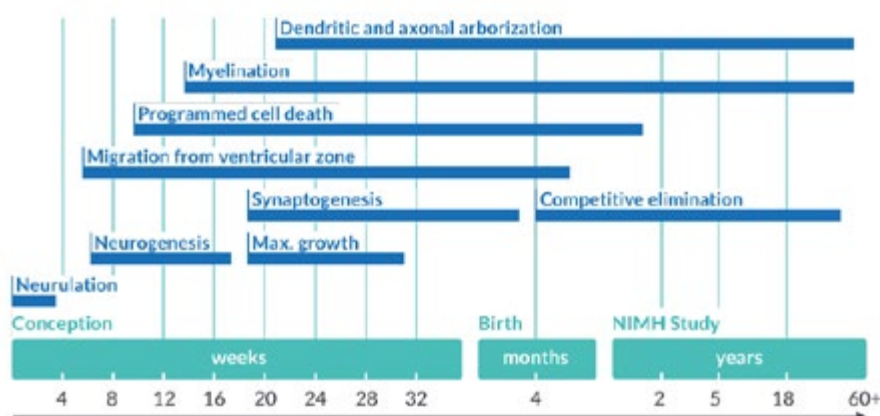
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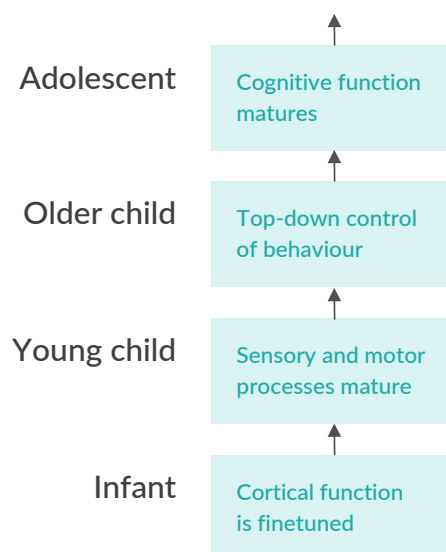
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DEVELOPMENT OF THE CENTRAL NERVOUS SYSTEM IN CHILDREN

Time course of critical events in the determination of human brain morphometry



(Reprinted from: *Neurosci Biobehav Rev.* Vol 30(6). Lenroot RK, Giedd JN. Brain development in children and adolescents: insights from anatomical magnetic resonance imaging. 718–29 (2006), with permission from Elsevier)



The dynamic interplay between progressive and regressive events results in relatively rapid brain growth in the first 2 years of life. By the age of 2, the brain has achieved 80% of its adult weight; by the age of 5, it has achieved 90%. However, significant remodelling of grey and white matter continues into the third decade of life, and areas such as the association cortex, which integrates memory, audio-visual inputs, and object recognition, matures later. The parts of the brain associated with complex decision-making, impulse control, error-checking and judgement are the latest to mature.

If a child's neurodevelopment is interrupted or impaired by environmental pollutants and indoor air pollutants, the health consequences can be serious. This may lead to a number of conditions and symptoms, including cognitive impairment (lower cognitive test outcomes), attention disorders and autism spectrum disorder, all of which are difficult to diagnose and treat and may have a lifelong impact.

References:

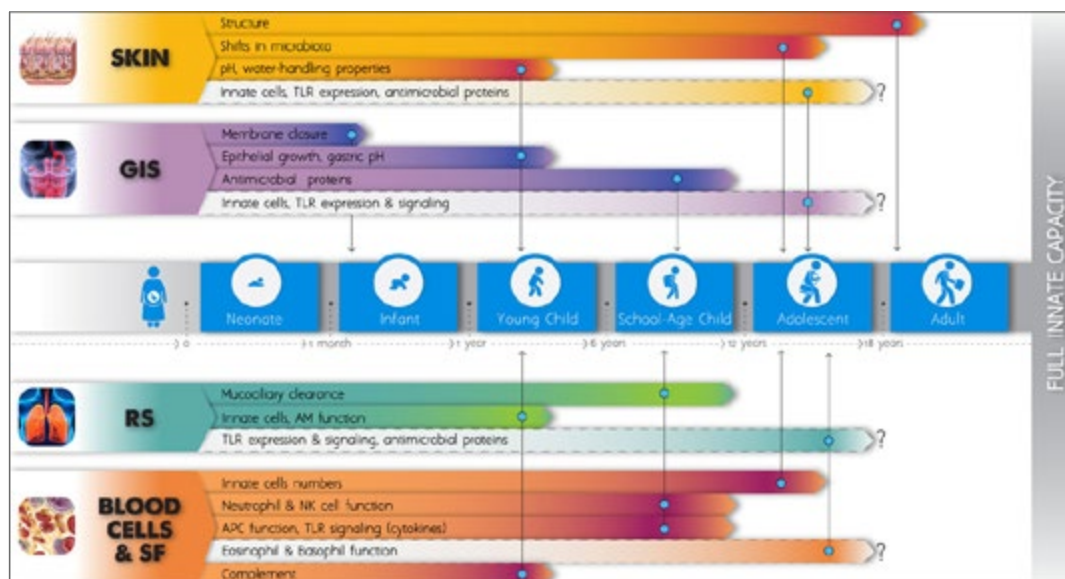
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DEVELOPMENT OF THE IMMUNE SYSTEM IN CHILDREN



(Reproduced without changes from Georgountzou A, Papadopoulos NG. Postnatal Innate Immune Development: From Birth to Adulthood. *Front. Immunol.* 8:957; 2017. HYPERLINK "<https://www.frontiersin.org/articles/10.3389/fimmu.2017.00957/full>" doi: 10.3389/fimmu.2017.00957. License: HYPERLINK "<https://creativecommons.org/licenses/by/4.0/>" CC BY 4.0)

*AM: antimicrobial; APC: antigen-presenting cell; GIS: gastrointestinal system; NK: natural killer; RS: respiratory system; SF: soluble factor; TLR: Toll-like receptor.

Children's immune systems are immature. Individual molecules, cells or pathways of innate recognition and signalling within different compartments/anatomical sites demonstrate variable maturation patterns. Early life exposure to environmental hazards can produce significant immunotoxicity, whereas the same effects are not always seen in adults. The consequences of early exposure could include increased susceptibility to infectious diseases and cancers, increased risk of asthma and atopy, and increased risk of some autoimmune diseases. Evidence suggests that the expected outcome of exposure can differ depending upon the window of immune development when exposure occurs. Hence, the developmental status of the immune system during environmental insult is a key factor in determining the likely health risk.

References:

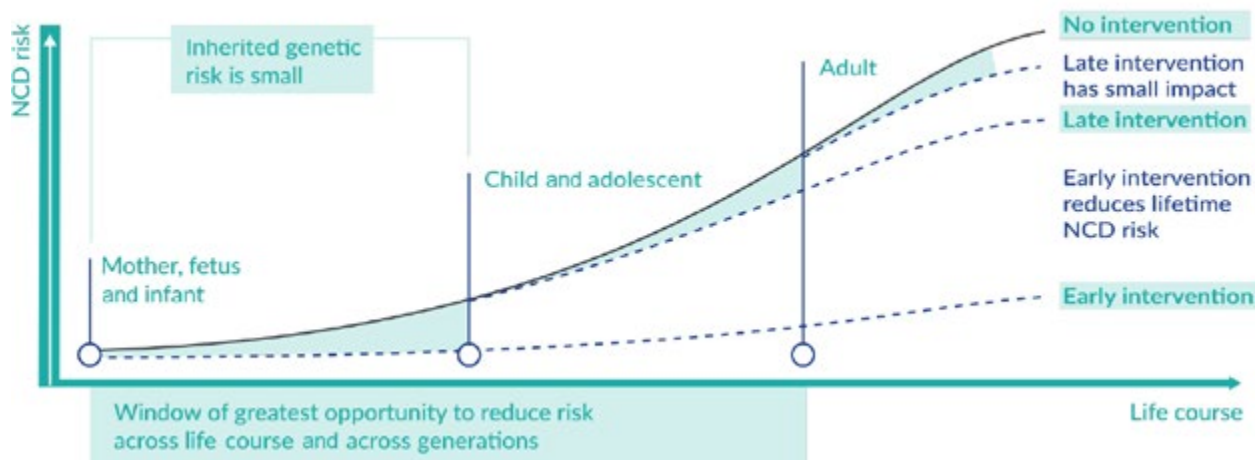
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LONGER LIFE EXPECTANCY

Lifecourse view of NCD risk reduction



(Source: Hanson AM (unpublished material). Published with permission of the author)

The trajectory of human life is affected by genetic, epigenetic and intrauterine legacies, by environmental exposures and by other factors. While inherited traits are important, new research shows that environmental stressors during vulnerable life stages play a key role in determining functional development and future disease risks. Noncommunicable diseases, which can be caused by exposure to indoor air pollutants, commonly have delayed onset. This relates to cancer, cardiovascular diseases and chronic obstructive pulmonary diseases. The maximum effect will be gained from timely interventions in early life when plasticity permits a sustained reduction in the trajectory of risk. Investment in early childhood development and protection against toxic stress and dangerous environmental exposures at critical points of development are among the most cost-effective policy choices available to governments.

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CHILDREN

DON'T HAVE A POWER

TO INFLUENCE DECISIONS

TO PROTECT THEMSELVES

References:

WHO (2017). Inheriting a sustainable world? Atlas on children's health and the environment. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/254677>, accessed 1 November 2019).



OTHER VULNERABLE/ SUSCEPTIBLE POPULATION GROUPS

- People with respiratory diseases, including asthma and chronic lung diseases
- People whose immune systems are suppressed due to chemo- or radiation therapy, disease, or other causes
- People with allergies
- People using certain types of medication
- People wearing contact lenses (higher risk of development of eye irritation)

References:

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Module 4



INDOOR AIR POLLUTION AND CHILDREN'S HEALTH

This module summarizes the information on linkages between indoor air pollution in schools, kindergartens and day-care centres and children's health as revealed in scientific studies.

PREREQUISITES OF HEALTH EFFECTS FROM EXPOSURE TO POLLUTANTS

Pollutant characteristics:

- Toxicity
- Concentration
- Distribution of certain pollutants between gaseous and particulate phases
- Duration of exposure
- Number of pollutants and their interaction

Individual characteristics:

- Age, gender and body weight
- Health status (for example, the presence of respiratory diseases; immune, hormonal, nutritional and central nervous system status)
- Genetic susceptibility
- Lifestyle

There are two main groups of factors determining the development of health disorders linked to exposure to air pollutants, including hazardous pollutants in indoor air. One group characterizes the properties of a pollutant (different target organs and toxicity) and characteristics of exposure (pathways, duration and frequency of exposure). Pollutants can be toxic to respiratory, immune, cardiovascular, neurological or blood systems, for example. Hence, health effects will depend on the specific toxicity of chemicals.

Commonly, a higher pollutant concentration is likely to represent an increased probability of the development of health disorders; however, there is evidence that many chemical pollutants can cause adverse effects even at low concentrations. In addition, the longer the exposure to the pollutant, the higher the likelihood that health disorders develop. Acting together, hazardous chemicals co-existing in the mixture to which the individual is exposed can demonstrate additive, synergistic or antagonistic effects.

The other main group of factors relates to the characteristics of the individual organism that determine susceptibility to environmental stressors. These include age, gender, health status, genetics and lifestyle.

References:

WHO (2006). Environmental Health Criteria 237. Principles for evaluating health risks in children associated with exposure to chemicals. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/43604>, accessed 1 November 2019).

EFFECTS FROM SHORT- AND LONG-TERM EXPOSURE

Short-term exposure:

- Headache
- Fatigue
- Shortness of breath
- Sinus congestion
- Coughing
- Sneezing
- Dizziness
- Asthmatic attacks
- Nausea
- Irritation of the eyes, nose, throat and skin

Long-term exposure:

- Allergies
- Asthma and other respiratory diseases
- Cancer

Symptoms and diseases caused by short- and long-term exposure to indoor air pollutants differ. Some can be irreversible and determine an individual's health status throughout the life course. Both short- and long-term effects have been associated with measured or estimated concentrations of indoor air pollutants. Several national and international research projects, including the School Environment and Respiratory Health of Children (SEaRCH) study, the Interventions on Health Effects of School Environment study and the SINPHONIE study investigated associations between exposure to air pollutants in public settings and respective health outcomes in children. In most of these studies, the relationship between poor indoor air quality and one or more health outcomes was observed.

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Health effects caused by exposure to pollutants in indoor air are linked both with exposure to individual compounds and with exposure to a mixture of pollutants.

Exposure to higher concentrations of pollutants is more likely to cause health effects.



THE MOST COMMON HEALTH EFFECTS OF INDOOR AIR POLLUTANTS ARE RESPIRATORY, NEUROLOGICAL, IRRITATIVE, IMMUNE.

The respiratory system disorders linked with indoor air pollution in public settings for children include irritation, change in lung function, asthma, lower respiratory tract infection (including severe acute lower respiratory infection), chronic bronchitis and, later in life, cancers and chronic obstructive pulmonary disorders. The prevalence of chronic bronchitis and asthmatic symptoms, acute low respiratory tract infections, increased level of pneumonia and decreased lung function – measured as forced vital capacity (FVC) and forced expiratory volume in the first second (FEV1) – is higher in children in schools with increased levels of indoor air pollution in comparison with those in schools with a lower level of pollution. Other effects include neurological and immune systems disorders, increased risk of cardiovascular diseases and carcinogenicity later in life.

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RESPIRATORY EFFECTS

Health disorder	Indoor air pollutants	Source of information
Dry cough, wheezing, rhinitis	VOCs, PM, formaldehyde, NO ₂	Simoni et al., 2010; Billonnet et al., 2011; Patelarou, Tzanakis & Kelly, 2015; Flamant-Hulin et al., 2010; Fraga et al., 2008
Acute low respiratory tract infections and increased risk of pneumonia	Formaldehyde, biomass fuel combustion products	Jackson et al., 2013; Dherani et al., 2008; Po et al., 2011
Low lung function – decreased air flow	Formaldehyde, benzyl butyl phthalates, sum of polybrominated diphenyl	Wallner et al., 2012
Irritating cough	Limonene, nitrogen oxides, PM _{2.5} , ozone	Csobod, Rudnai & Vasconi, 2010
Low forced vital capacity (FVC) and forced expiratory volume in the first second (FEV1)	Ethylbenzene, m-, p- and o-xylene	Wallner et al., 2012

There is evidence of associations between the concentration of certain chemicals and PM in indoor air in schools and different types of health disorders in children, including the examples presented below and on the slide.

- Nasal patency has measured significantly lower in schoolchildren exposed to concentrations of PM₁₀ higher than 50 µg/m³ than in those exposed to lower levels.
- A negative association has been found between airflow in the lungs of schoolchildren and formaldehyde in air. Formaldehyde in classrooms has been significantly related to dry throat, nasal allergy and phlegm in children.
- Ethylbenzene, m-, p-xylene and o-xylene in indoor air have shown significant negative correlations with FVC and forced FEV1, which are key indicators of lung function.
- Benzene, naphthalene, limonene, trichloroethylene and tetrachloroethylene have been related to irritation symptoms and to nasal allergy and wheezing in children.
- The concentrations of VOCs have been related to chronic airway symptoms.
- Nitrogen dioxide has been associated with irritative cough, wheezing and asthma attacks.
- Ozone in classrooms has been related to sore throat and irritative cough in children.

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continued

RESPIRATORY EFFECTS		
Health disorder	Indoor air pollutants	Source of information
Dry cough, wheezing, rhinitis	VOCs, PM, formaldehyde, NO ₂	Simoni et al., 2010; Billionnet et al., 2011; Patelarou, Tzanakis & Kelly, 2015; Flamant-Hulin et al., 2010; Fraga et al., 2008
Acute low respiratory tract infections and increased risk of pneumonia	Formaldehyde, biomass fuel combustion products	Jackson et al., 2013; Dherani et al., 2008; Po et al., 2011
Low lung function – decreased air flow	Formaldehyde, benzyl butyl phthalates, sum of polybrominated diphenyl	Wallner et al., 2012
Irritating cough	Limone, nitrogen oxides, PM _{2.5} -sulfate	Csobod, Rudnai & Vaskovi, 2010
Low forced vital capacity (FVC) and forced expiratory volume in the first second (FEV1)	Ethylbenzene, m-, p- and o-xylene	Wallner et al., 2012

Csobod E, Rudnai P, Vaskovi E, editors (2010). School Environment and Respiratory Health of Children (SEaRCH) international research project report within the programme “Indoor air quality in European schools: preventing and reducing respiratory diseases”. Szentendre: Regional Environmental Center for Central and Eastern Europe (http://search.rec.org/search1/doc/SEARCH%20publication_EN_final.pdf, accessed 29 June 2020).

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RESPIRATORY AND IMMUNE SYSTEM EFFECTS (I)

Health disorder	Indoor air pollutants	Source of information
Asthma, exercise-induced asthma, allergic asthma, exacerbation of asthma, hospital admission due to asthma	PM, acrolein, nitrogen oxides, sulfur dioxide, carbon monoxide, VOCs, benzene, formaldehyde, toluene, aromatic and aliphatic hydrocarbons	Annesi-Maesano et al., 2012; Karimi et al., 2015; Patelarou, Tzanakis & Kelly, 2015; Hulin, Caillaud & Annesi-Maesano, 2010; Pénard-Morand et al., 2010; Zhang et al., 2019; Fraga et al., 2008; Wang et al., 2009
Asthma-like/asthma-related symptoms	VOCs, PM _{2.5} , PM ₁₀	Madureira et al., 2015; Kotzias et al., 2005
Risk of lifetime asthma	Benzene, PM ₁₀	Pénard-Morand et al., 2010
Risk of allergies, sensitization	Formaldehyde	Hulin, Caillaud & Annesi-Maesano, 2010; Casset et al., 2006

The rapid rise in prevalence of allergic respiratory diseases (allergic asthma, allergic rhinitis) in recent decades cannot be explained by genetic factors. Allergic diseases are more common among urban residents and growing evidence shows that air pollution may contribute to the development of allergic diseases. Susceptibility to allergens may increase in the presence of certain air pollutants. In this regards, both indoor and outdoor air pollutants can trigger airway inflammation, thus increasing the severity of allergy and asthma.

Many publications have highlighted the ability of pollutants to modulate the immune response. The inhalation of PM and gaseous pollutants impacts both the innate and adaptive defence systems of the lungs. In addition, pollutant-induced alterations in receptors' recognition of pathogens may contribute to the increased susceptibility and severity of viral infections, and to the development of airway diseases such as asthma.

Exposure to formaldehyde can increase the risk of allergies and sensitization. A significant positive correlation has also been found between concentrations of PM_{2.5} and acrolein in schools and exercise-induced asthma. Concentrations of benzene, sulfur dioxide, PM₁₀, nitrogen oxides and carbon monoxide have been significantly positively associated with asthma (exercise-induced, past year and lifetime). PAHs have also been linked to asthma development and exacerbation through the promotion of oxidative stress and immune responses.

Associations of lifetime asthma with benzene, sulphur dioxide and PM₁₀, and of sensitization to pollens with PM₁₀ are particularly robust.

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continued

RESPIRATORY AND IMMUNE SYSTEM EFFECTS (I)		
Health disorder	Indoor air pollutants	Source of information
Asthma, exercise-induced asthma, allergic asthma, exacerbation of asthma, hospital admission due to asthma	PM, acrolein, nitrogen oxides, sulfur dioxide, carbon monoxide, VOCs, benzene, formaldehyde, toluene, aromatic and aliphatic hydrocarbons	Annesi-Maesano et al., 2012; Karimi et al., 2015; Patelarou, Tzanakis & Kelly, 2015; Hulin, Caillaud & Annesi-Maesano, 2010; Pénard-Morand et al., 2010; Zhang et al., 2019; Fraga et al., 2008; Wang et al., 2009
Asthma-like/asthma-related symptoms	VOCs, PM _{2.5} , PM ₁₀	Madureira et al., 2015; Kotzias et al., 2005
Risk of lifetime asthma	Benzene, PM ₁₀	Pénard-Morand et al., 2010
Risk of allergies, sensitization	Formaldehyde	Hulin, Caillaud & Annesi-Maesano, 2010; Casset et al., 2006

Fraga S, Ramos E, Martins A, Samúdio MJ, Silva G, Guedes J et al. (2008). Qualidade do ar interior e sintomas respiratórios em escolas do Porto [Indoor air quality and respiratory symptoms in Porto schools]. *Revista Portuguesa de Pneumologia*. 14(4):487–507 (in Portuguese). doi:10.1016/S0873-2159(15)30254-3.

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RESPIRATORY AND IMMUNE SYSTEM EFFECTS (II)

Health disorder	Indoor air pollutants	Source of information
Increased susceptibility to viral infections and pollutant-induced pathogenesis of airway diseases such as asthma	PM	Bauer, Diaz-Sanchez & Jaspers, 2012; Lee et al., 2015
Allergic rhinitis	PM ₁₀ , PM _{2.5} , trichloroethylene, tetrachloroethylene	Pénard-Morand et al., 2010; SINPHONIE & Regional Environmental Center for Central and Eastern Europe, 2014; Wang et al., 2009
Sensitization to pollen	Benzene, PM ₁₀	Pénard-Morand et al., 2010

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NEUROLOGICAL EFFECTS

Health disorder	Indoor air pollutants	Source of information
Headache and fatigue	VOCs;	Norbäck et al., 2017
Subclinical changes on the caudate nucleus (cognitive and behavior processes)	PAHs (benzo[a]pyrene)	Mortamais et al., 2017; BREATHE
Poorer performance on neurobehavioral tests	NO ₂ , PM ₁₀ , black carbon	Wang et al., 2009
Smaller growth in cognitive development	NO ₂ , ultrafine particle, environmental tobacco smoke	Sunyer et al., 2015; Forns et al., 2017; Youlton et al., 2005

Neural development (proliferation, migration, differentiation, myelination of neurons, synaptogenesis, and regulated apoptosis) extends from the embryonic period through adolescence. This period is a critical developmental window when air pollution can act as a neurodevelopmental toxicant. The most neurotoxic chemicals among air pollutants are certain VOCs and PAHs.

VOCs in schools have been found to be risk factors for symptoms of sick building syndrome, such as headache and fatigue. Exposure to PAHs, in particular to benzo[a]pyrene, in the school environment during the preadolescent school-age years is associated with subclinical changes in the caudate nucleus (based on magnetic resonance imaging (MRI) assessment and air quality monitoring), which plays a crucial role in many cognitive and behavioural processes. Children from schools in areas with severe traffic-related air pollution of NO₂ and PM₁₀ have shown significantly poorer performance on neurobehavioural tests. Children from highly polluted schools have also shown significantly smaller growth in cognitive development.

References:

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continued

NEUROLOGICAL EFFECTS		
Health disorder	Indoor air pollutants	Source of information
Headache and fatigue	VOCs	Norback et al., 2017
Subclinical changes on the caudate nucleus (cognitive and behavior processes)	PAHs (benzo[a]pyrene)	Mortamais et al., 2017; BREATHE
Poorer performance on neurobehavioral tests	NO ₂ , PM _{2.5} , black carbon	Wang et al., 2009
Smaller growth in cognitive development	NO ₂ , ultrafine particle, environmental tobacco smoke	Sunyer et al., 2015; Forns et al., 2017; Youlton et al., 2005

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CARDIOVASCULAR EFFECTS

Health disorder	Indoor air pollutants	Source of information
Increased blood pressure – later-life hypertension	PM ₁₀ and PM _{2.5} , nitrogen oxides, ozone, black carbon, environmental tobacco smoke, phthalates, traffic-related air pollution	Sanders et al., 2018; Sughis et al., 2012

Less is known about the association between air pollution and changes in cardiovascular parameters in children; however, the environment of children's homes and schools may contribute to the development of long-term health effects. For example, later-life hypertension is correlated with early-life blood pressure elevation due to air pollution.

References:

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CANCER RISK

- Four chemicals commonly found in indoor air are known as human carcinogens: benzene, trichloroethylene, formaldehyde, and benzo(a)pyrene.
- Higher age-adjusted cancer risks have been estimated using different approaches.
- Two other chemicals – styrene and tetra-chloroethylene – are classified as possible or probable human carcinogens.

A growing amount of information suggests that early-life exposures to air pollution may contribute to later-life diseases, including cancer; however, the mechanisms accounting for this are not yet fully clear. Among VOCs found in indoor air (which may originate either indoors or outdoors), benzene, trichloroethylene and formaldehyde have been classified as known human carcinogens by the IARC based on evidence from epidemiologic studies and animal data, while styrene and tetrachloroethylene have been classified as possible or probable carcinogens for humans, respectively.

Benzene is toxic to bone marrow and is associated with various haematological cancers. Formaldehyde may cause nasal cancer and leukemia. Among PAHs commonly presented in indoor air benzo[a]pyrene has been classified as a known human carcinogen, and naphthalene as possible carcinogens. These may induce cancerous tumours, primarily in the lungs, skin, bladder, liver and stomach.

A growing number of studies have been published in the last years regarding several air pollutant exposures in schools and cancer risk estimates based on child-specific benchmark levels. According to health risk assessments, formaldehyde is the most concerning pollutant with high chronic toxic and carcinogenic risk levels, followed by naphthalene, benzene and toluene due to their chronic effects. Investigation of 38 volatile organic compounds in 34 early-childhood educational environments revealed that child exposures to benzene, chloroform, ethylbenzene and naphthalene exceeded age-adjusted benchmark levels of cancer risks (based on California's Proposition 65 guidelines' 10^{-5} lifetime cancer risk) in 71%, 38%, 56%, and 97% of facilities, respectively.

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CANCER RISK

- Four chemicals commonly found in indoor air are known as human carcinogens: benzene, trichloroethylene, formaldehyde, and benzol(a)pyrene.
- Higher age-adjusted cancer risks have been estimated using different approaches.
- Two other chemicals – styrene and tetra-chloroethylene – are classified as possible or probable human carcinogens.

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SYMPTOMS ASSOCIATED WITH EXPOSURE TO POLLUTANTS IN INDOOR AIR (I)

Pollutant	Symptoms	
	School-aged children	Kindergarten-aged children
Formaldehyde	Irritation of skin and face, nasal congestion, dry cough at night (exposure of more than 12 months)	Dry mouth, allergic rhinitis (exposure of more than 12 months), itchy rash (exposure of more than 6 months), eczema, phlegm formation
Benzene	Irritation of skin, eczema	Allergic rhinitis, irritation, sore throat, eczema
Naphthalene	Itching of skin, tiredness, bad mood (lack of energy)	–
Limonene	Irritation of skin, rhinitis, nasal congestion, sore throat, irritating cough, chills/fever, eczema, nausea, fatigue and bad mood (lack of energy), eye irritation (exposure of more than 12 months)	–

The SINPHONIE study in the European Union observed differences in symptoms among children in schools and kindergartens in response to exposure to the same pollutants, which confirms the need for age-specific studies, diagnosis, treatment and risk-reduction measures.

References:

Csobod E, Annesi-Maesano I, Carrer P, Kephelopoulos S, Madureira J, Rudnai P et al (2014). SINPHONIE (Schools Indoor Pollution and Health Observatory Network in Europe): Final report. Luxembourg: Publications Office of the European Union (<https://op.europa.eu/en/publication-detail/-/publication/b1243a1b-317b-422f-b6cf-645b693b3cdf/language-en>, accessed 1 November 2019).

SYMPTOMS ASSOCIATED WITH EXPOSURE TO POLLUTANTS IN INDOOR AIR (II)

Pollutant	Symptoms	
	School-aged children	Kindergarten-aged children
Trichloro-ethylene	Rashes and itching of skin, irritation and swelling of the eyes, headache, sore throat, tiredness, chills/fever	Eye irritation, allergic rhinitis, wheezing (exposure of more than 12 months)
Tetrachloro-ethylene	Itchy skin, sore throat, wheezing (exposure of more than 30 days), allergic rhinitis (exposure of more than 12 months)	Pain in the throat
NO ₂	Itchy skin, rash on face, eczema, chills/fever	Irritating cough
Ozone	Feeling tired and depressed, wheezing, nasal congestion, allergic rhinitis (exposure of more than 12 months), itchy rash (exposure of more than 6 months), asthmatic attacks	Sore throat, irritating cough

Some specific characteristics can signal unhealthy indoor air in schools in cases of short-term exposure. These should be considered when determining the cause of acute health disorders in children, and immediate measures should be taken to protect children and staff from the negative impacts of chemical pollutants.

References:

Kephalopoulos S, Csobod E, Bruinen de Bruin Y, De Oliveira Fernandes E (2014). Guidelines for healthy environments within European schools Luxembourg: European Commission's Directorates General for Health and Consumers and Joint Research Centre (<https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/guidelines-healthy-environments-within-european-schools>, accessed 1 November 2019).

CASE STUDY: ENDOCRINE-DISRUPTING CHEMICALS IN INDOOR AIR – CHILDHOOD ASTHMA, OBESITY AND RESPIRATORY SYMPTOMS (I)

- O-xylene
- M/p-xylene
- Toluene
- Ethylbenzene
- Styrene
- Benzene

- Butylated hydroxytoluene
- Formaldehyde
- Acetaldehyde
- Cyclohexanone
- Benzene
- Benzaldehyde

This study involved a self-administered questionnaire based on the International Study of Asthma and Allergies in Children (ISAAC) covering social, demographic and behavioural characteristics and respiratory/allergic symptoms.

It measured:

- anthropometry (height, weight, body fat mass, total body water);
- lung function and airway reversibility (spirometry);
- airway inflammation (fractional exhaled nitric oxide level); and
- nervous system (pupillometry).



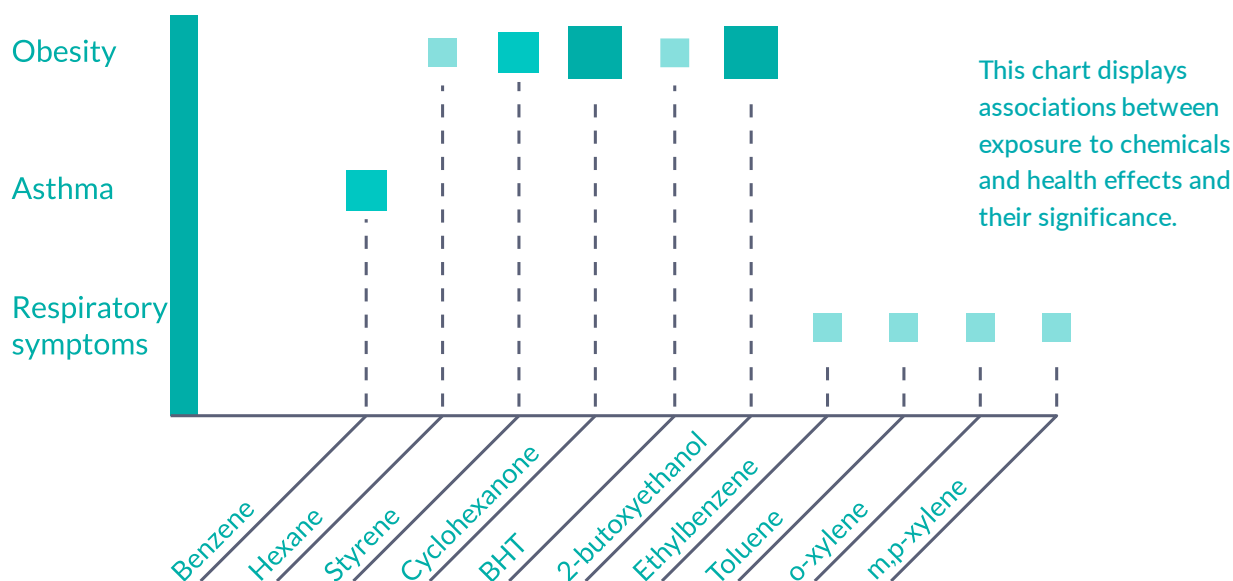
71 classrooms
from 20 primary schools
815 children aged 7–12 years

In this case study, researchers considered data from a cross-sectional analysis of 815 school-age children from 20 schools in Portugal. They assessed symptoms through questionnaires and made clinical evaluations mainly to determine asthma according to lung function, and calculate airway reversibility and body mass index (BMI). They measured concentrations of 13 VOCs and 2 aldehydes identified as endocrine-disrupting chemicals (EDCs) in 71 classrooms throughout one week. The team used principal component analysis (PCA) to assess the effect of co-exposure, and estimated associations by regression coefficients using linear and logistic regression models.

References:

Paciência I, Cavaleiro Rufo J, Silva D, Martins C, Mendes F, Farraia M et al. (2019). Exposure to indoor endocrine-disrupting chemicals and childhood asthma and obesity. *Allergy*. 74(7):1277–91. doi:10.1111/all.13740.

CASE STUDY: ENDOCRINE-DISRUPTING CHEMICALS IN INDOOR AIR – CHILDHOOD ASTHMA, OBESITY AND RESPIRATORY SYMPTOMS (II)



(Paciência, I, Cavaleiro Rufo, J, Silva, D, et al. Exposure to indoor endocrine-disrupting chemicals and childhood asthma and obesity. *Allergy*. 2019; 74: 1277– 1291. doi: HYPERLINK "https://doi.org/10.1111/all.13740" 10.1111/all.13740)

Toluene, o-xylene, m-,p-xylene and ethylbenzene were significantly associated with nasal obstruction. Higher levels of hexane, styrene, cyclohexanone, butylated hydroxytoluene and 2-butoxyethanol were associated with obesity, and higher levels of cyclohexanone were associated with increased child BMI. The study also found increased individual and combined EDC levels in classrooms where more children had asthma and obesity.

References:

Paciência I, Cavaleiro Rufo J, Silva D, Martins C, Mendes F, Farraia M et al. (2019). Exposure to indoor endocrine-disrupting chemicals and childhood asthma and obesity. *Allergy*. 74(7):1277–91. doi:10.1111/all.13740.

SUMMARY OF MODULE 4

- Indoor air pollution can cause short- and long-term health effects in children.
- Epidemiological studies have reported evidence of the negative impacts of air pollution on respiratory, nervous and immune systems.
- Links have been found between health disorders and both individual pollutants and indoor air quality in general.
- Symptoms associated with indoor air pollutants can differ depending on children's age.

Module 5

HEALTH RISK ASSESSMENT



HEALTH RISKS FOR CHILDREN: RELEVANCE TO INDOOR AIR POLLUTION

- Both outdoor and indoor environments of schools, kindergartens and day-care centres are important determinants of children's health.
 - Children spend 70–90% of their time indoors.
 - Transgressions of WHO guideline values of PM, formaldehyde and benzene have been reported in schools and public settings for children in many studies in Europe.
- For example, in the 2011 SINPHONIE study:**
- only 40% of children were exposed to PM_{2.5} of less than 10 µg/m³;
 - around 25% of children were exposed to benzene in schools at concentration levels greater than 5 µg/m³ (the lifetime risk of leukaemia at an air concentration of 1 µg/m³ is 6x10⁻⁶); and
 - 10% of children were exposed to trichloroethylene in schools at concentration levels greater than 5 µg/m³ (the lifetime cancer risk at an air concentration of 1 µg/m³ is 4.3x10⁻⁷).

As reported in many studies around Europe and globally, the likelihood of health risks of indoor air pollution is high.

References:

Csobod E, Annesi-Maesano I, Carrer P, Kephelopoulos S, Madureira J, Rudnai P et al (2014). SINPHONIE (Schools Indoor Pollution and Health Observatory Network in Europe): Final report. Luxembourg: Publications Office of the European Union (<https://op.europa.eu/en/publication-detail/-/publication/b1243a1b-317b-422f-b6cf-645b693b3cdf/language-en>, accessed 1 November 2019).

Fournier K, Tebby C, Zeman F, Glorennec P, Zmirou-Navier D, Bonvallot N (2016). Multiple exposures to indoor contaminants: derivation of benchmark doses and relative potency factors based on male reprotoxic effects. *Regul Toxicol Pharmacol.* 74:23–30. doi:10.1016/j.yrtph.2015.11.017.

Pelletier M, Glorennec P, Mandin C, Le Bot B, Ramalho O, Mercier F et al. (2018). Chemical-by-chemical and cumulative risk assessment of residential indoor exposure to semivolatile organic compounds in France. *Environ Int.* 117:22–32. doi:10.1016/j.envint.2018.04.024.

Scientific Committee on Health and Environmental Risks (SCHER), Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), Scientific Committee on Consumer Safety (SCCS) (2011). Toxicity and assessment of chemical mixtures. Luxembourg: European Commission Directorate-General for Health & Consumers (http://ec.europa.eu/health/scientific_committees/environmental_risks/docs/scher_o_155.pdf, accessed 1 November 2019).

WHO Regional Office for Europe (2010). WHO guidelines for indoor air quality. Selected pollutants. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/260127>, accessed 1 November 2019).

WHO Regional Office for Europe (2019). Towards a tool for assessment of cumulative risks from indoor air pollutants in public settings for children: the first expert consultation. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0020/410780/Indoor-air-pollutants-public-children-first-consultation-report.pdf, accessed 1 November 2019).

DEFINITIONS (WHO)

Risk: The probability of an adverse effect in an organism, system or (sub)population caused under specific circumstances by exposure to an agent

Human health risk assessment: A process intended to estimate the risk to a given target organism, system or (sub)population, including the identification of attendant uncertainties, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system

Combined action: The joint effects of two or more chemicals

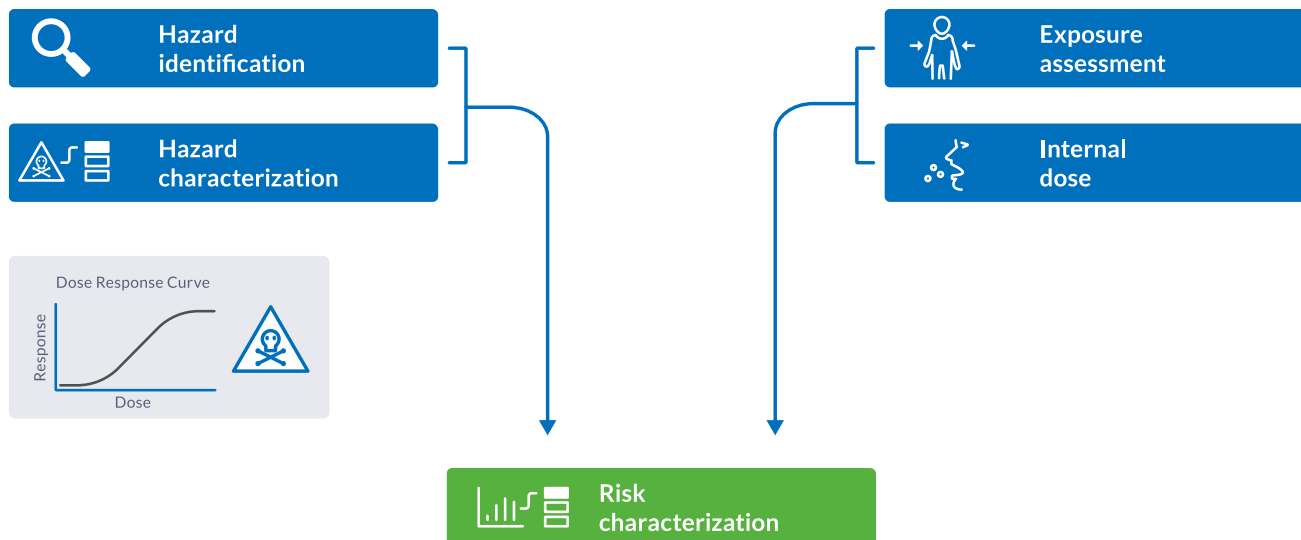
Combined exposure to multiple chemicals: Exposure to multiple chemicals by a single route of exposure and exposure to multiple chemicals by multiple routes; this covers temporal and nontemporal co-exposure

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO (2017). Chemical mixtures in source water and drinking-water. Geneva: World Health Organization; 2017 (<https://apps.who.int/iris/handle/10665/255543>, accessed 1 November 2019).

HUMAN HEALTH RISK ASSESSMENT: GENERIC APPROACH



Human health risk assessment of chemicals refers to methods and techniques for the evaluation of the hazards, exposure and harm posed by chemicals. The risk assessment process begins with problem formulation and includes the following four steps.

1. Hazard identification: identification of the potential of a substance to cause adverse health effects
2. Hazard characterization: qualitative or quantitative characterization of the potential of an agent to cause adverse health effects
3. Exposure assessment: evaluation of concentration or amount of a particular agent that reaches a target population
4. Risk characterization: integration of hazard characterization and exposure assessment to estimate risk of adverse effects, including uncertainties

The paradigm for risk assessment is the same for individual chemicals and chemical mixtures.

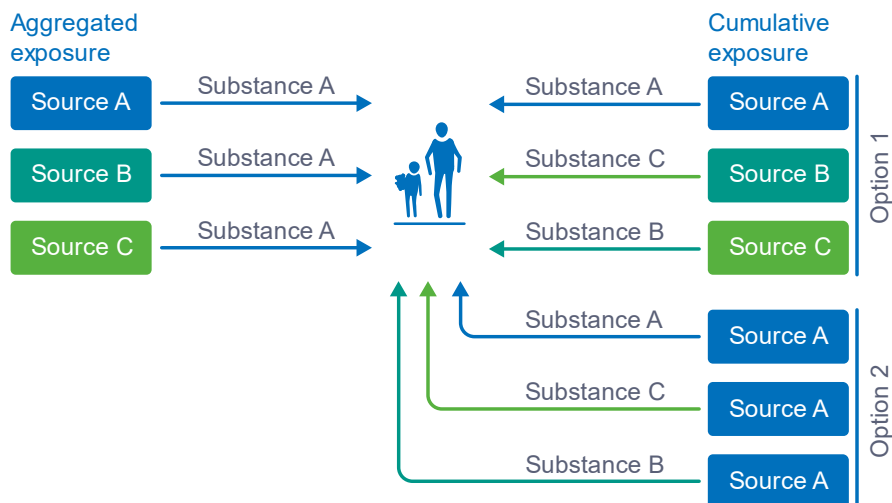
References:

WHO (2010). WHO Human health risk assessment toolkit: chemical hazards. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/44458>), accessed 1 November 2019).

WHAT ARE COMBINED EFFECTS?

The effect of the combined exposure to chemicals is the response of the biological system to the simultaneous, sequential or integrated effect of more than one substance from sources in the external environment.

- Includes exposure by multiple pathways and routes (referenced in some countries as “aggregate exposure”).
- Includes multiple chemicals by multiple routes.



The terminology related to combined exposure was agreed at an expert meeting organized by WHO in 2009 as follows.

Exposure to the same substance from multiple sources and by multiple pathways and routes is likely best described as “single chemical, all routes” (referenced in some jurisdictions as “aggregate” exposure).

Similarly, it is recommended that exposure to “multiple chemicals by a single route” be distinguished from exposure to “multiple chemicals by multiple routes” (referenced in some jurisdictions as “cumulative” exposure). To this end, the presented framework addresses “combined exposure to multiple chemicals” — i.e., exposure to multiple chemicals by a single route and exposure to multiple chemicals by multiple routes. Substances grouped together for evaluation of combined exposure are referenced as an “assessment group”.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO, United Nations Environment Programme (UNEP), International Labour Organization (ILO) (2009). Assessment of combined exposures to multiple chemicals: report of a WHO/IPCS international workshop on aggregate/cumulative risk assessment. Geneva: World Health Organization (<http://www.who.int/ipcs/methods/harmonization/areas/workshopreportdocument7.pdf>, accessed 12 May 2021).

COMBINED EXPOSURE TO MULTIPLE CHEMICALS– RELEVANCE TO INDOOR AIR POLLUTION

- In reality, humans are continuously exposed to a wide variety of chemicals.
- In indoor air, 90 substances were identified in schools and kindergartens by European studies between 2012 and 2017.
- Hazardous chemicals were found in all measurements of indoor air pollution.
- There is a high likelihood of co-exposure.
- The cumulative risk of multiple substances is higher than the risk of individual chemicals.

References:

De Brouwere K, Cornelis C, Arvanitis A, Brown T, Crump D, Harrison P et al. (2014). Application of the maximum cumulative ratio (MCR) as a screening tool for the evaluation of mixtures in residential indoor air. *Sci Total Environ.* 479–80(1):267–76. doi:10.1016/j.scitotenv.2014.01.083.

Mishra N, Ayoko GA, Salthammer T, Morawska L (2015). Evaluating the risk of mixtures in the indoor air of primary school classrooms. *Environ Sci Pollut Res Int.* 22(19):15080–8. doi:10.1007/s11356-015-4619-z.

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WHO Regional Office for Europe (2019). Towards a tool for assessment of cumulative risks from indoor air pollutants in public settings for children: the first expert consultation. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0020/410780/Indoor-air-pollutants-public-children-first-consultation-report.pdf, accessed 1 November 2019).

COMBINED EXPOSURES

There are three types of combined action of chemicals:

1. dose addition (components act toxicologically similar – this is often the default assumption)
2. independent joint action
3. interactive actions:
 - synergy: effects are greater than expected from dose addition
 - antagonism: effects are less than expected from dose addition.



In recent years, in connection with the expansion of research to assess the effects of complex mixtures of chemical compounds (cumulative exposure) and the transition to risk assessment of “real-life exposure”, the attention of scientists across the globe has focused on the important problem of studying the joint action of chemicals.

The grouping of chemicals, taking into account the potential for joint exposure and the possibility of a combined toxic effect, is one of the most important issues when conducting a human health risk assessment procedure for a combined exposure. Combined action comprises settings in which:

- multiple substances act simultaneously; and
- multiple substances act sequentially.

Chemicals that act by the same mode of action and/or at the same target cell, tissue or organ often act in a potency-corrected “dose additive” manner. Alternatively, chemicals may act independently, by discrete modes of action or at different target cells, tissues or organs (independent joint action). Chemicals may also interact to produce an effect greater than that predicted on the basis of additivity (comprising synergy) or an effect less than that predicted on the basis of additivity (comprising antagonism).

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO, UNEP, ILO (2009). Assessment of combined exposures to multiple chemicals: report of a WHO/IPCS international workshop on aggregate/cumulative risk assessment. Geneva: World Health Organization (<http://www.who.int/ipcs/methods/harmonization/areas/workshopreportdocument7.pdf>, accessed 12 May 2021).

ADDITIVITY PRINCIPLE FOR ASSESSING COMBINED EFFECTS OF CHEMICALS

- Additivity is the assumed predominant type of combined action if the endpoints of adverse effects are the same.
- Additivity is unlikely if chemicals with different adverse-effect endpoints and different structures are mixed.
- Additivity is also common for chemicals with structural similarities (organophosphates, dioxins, pesticides, PAHs, etc.).
- As the main criteria for assessing combined exposure risks, WHO recommends using the hazard index (HI), the margin of exposure (MOE), and the toxic equivalency factor (TEF) or potency equivalency factor (PEF).

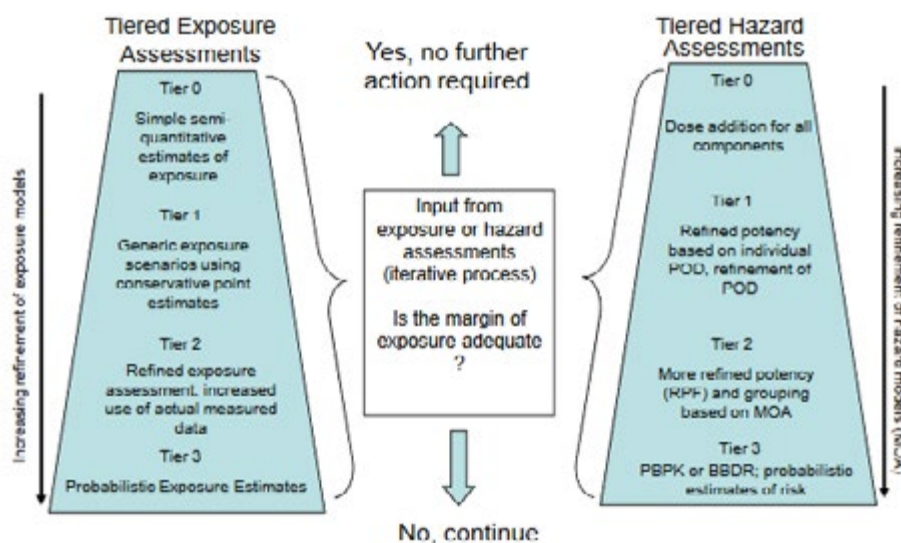
The possibility of synergism or antagonism is disregarded at this stage. This assumption stems from the fact that the degree of synergism or antagonism cannot be predicted quantitatively on the basis of the toxicity of the mixture components. All existing mixture effect prediction methods, and accordingly, all cumulative risk assessment models, assume additivity.

References:

Kortenkamp A, Backhaus T, Faust M (2009). State of the art report on mixture toxicity. Final report. Luxembourg: Publications Office of the European Commission (http://ec.europa.eu/environment/chemicals/effects/pdf/report_mixture_toxicity.pdf, accessed 1 November 2019).

WHO INTERNATIONAL PROGRAMME ON CHEMICAL SAFETY (IPCS) FRAMEWORK

Problem Formulation → Grouping of Chemicals for Combined Exposure Assessment



(Reproduced by permission of the authors from Meek et al., 2011)

In 2011, the WHO International Programme on Chemical Safety (IPCS) developed a framework for risk assessment of combined exposure to multiple chemicals (see on the slide). The framework builds on developments in a range of programmes internationally. A multitiered approach (4 tiers – Tier 0, Tier 1, Tier 2, Tier 3) is key to the framework: the initial level begins with simple but conservative assumptions for both exposure and hazard and develops to more complex exposure and hazard models. It was designed to aid risk assessors in identifying priorities for risk management for a wide range of applications where co-exposures to multiple chemicals are expected.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO, UNEP, ILO (2009). Assessment of combined exposures to multiple chemicals: report of a WHO/IPCS international workshop on aggregate/cumulative risk assessment. Geneva: World Health Organization (<http://www.who.int/ipcs/methods/harmonization/areas/workshopreportdocument7.pdf>, accessed 12 May 2021).

WHO IPCS FRAMEWORK

Objective

- Maximize efficiency in the consideration and generation of available information.
 - Only generate data that is needed.
- Ensure a fit-for-purpose assessment.
 - Assure that only necessary resources are invested to make a decision.
 - Set aside low priorities.
 - Identify groups for risk management.

Key issues

- Use an integrated (exposure/hazard) and iterative (tiered) approach.
- Work on increasing refinement/level of detail.
 - Generate data that is less conservative and uncertain.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

RISK ASSESSMENT: TERMINOLOGY AND DEFINITIONS

Hazard: intrinsic toxicity, that is the potential to cause adverse health effects

Point of departure (POD): a selected measure of effect that can be used as a basis for a risk assessment or assessment of a limit value (for example, acceptable daily intake (ADI), toxicological threshold, NOAEL, BMD)

No-observed-adverse-effect level (NOAEL): highest exposure level in a study at which no adverse health effects are observed (no statistically significant difference from the control group)

Lowest-observed-adverse-effect level (LOAEL): lowest exposure level in a study at which adverse health effects are observed (statistically significant difference from the control group – to be used in the absence of a NOAEL)

Benchmark dose (BMD): the dose associated with a specific increase in the magnitude or incidence of an effect (for example, 1% or 10%)

References:

WHO (2017). Chemical mixtures in source water and drinking-water. Geneva: World Health Organization (<https://apps.who.int/iris/bitstream/handle/10665/255543/9789241512374-eng.pdf?sequence=1>, accessed 1 November 2019).

PROBLEM FORMULATION

The condition of the application of the Framework



The potential effect of the simultaneous presence and combined impact of multiple chemicals

Questions

1. What is the nature of exposure?
2. Is exposure likely, taking into account the context?
3. Is co-exposure likely within a relevant timeframe?
4. What is the rationale for considering compounds in an assessment group?



Lack of information impedes the analysis, BUT

it does not eliminate the need to introduce measures to reduce exposure to chemicals.

Before applying the tiered approach and calculating risks, researchers must determine the applicability of the methodological scheme. This should be done through problem formulation. The potential impact of the co-occurrence of, and concomitant exposure to, multiple chemicals should always be taken into account in problem formulation for combined exposures risk assessment.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. Regul Toxicol Pharmacol. 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

CASE STUDY:

INDOOR AIR IN SCHOOLS (I)

Question 1:

What is the nature of exposure?

Combined exposure of children to co-occurring chemicals in schools through inhalation of indoor air.

- One route of exposure, many chemicals.
- Exposure occurs when children attend classes.
- The most common chemicals in the indoor air of schools are known.
- The same chemicals can be found in the majority of schools and classes.

The WHO Regional Office for Europe has developed a screening tool for assessment of risks to children's health from combined exposure to hazardous chemicals in indoor air in public settings for children; this and other slides provide an example of formulating the problem in relation to grouping of chemicals in indoor air for assessment of risk.

References:

WHO Regional Office for Europe (2019). Towards a tool for assessment of cumulative risks from indoor air pollutants in public settings for children: the first expert consultation. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0020/410780/Indoor-air-pollutants-public-children-first-consultation-report.pdf, accessed 1 November 2019).

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

CASE STUDY:

INDOOR AIR IN SCHOOLS (II)

Question 2:

Is exposure unlikely or very low?

No, there is a potential risk of co-exposure of children to pollutants in indoor air.

- Exposure to at least one hazardous chemical in indoor air was reported in all studies conducted so far.
- Quantifiable measurements were performed in many studies at national and multicountry levels.

References:

WHO Regional Office for Europe (2019). Towards a tool for assessment of cumulative risks from indoor air pollutants in public settings for children: the first expert consultation. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0020/410780/Indoor-air-pollutants-public-children-first-consultation-report.pdf, accessed 1 November 2019).

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

CASE STUDY:

INDOOR AIR IN SCHOOLS (III)

Question 3:

Is there a likelihood of co-exposure within a relevant time frame?

Yes, studies conducted globally and in the WHO European Region have confirmed the presence of at least two chemicals that can pose a risk to human health in the indoor air of schools – independent of geographical location and income level.

Question 4:

What is the rationale for considering compounds in an assessment group?

Hazardous chemicals in indoor air have the potential to act on the same target cell, tissue or organ (this is the basis for grouping of chemicals). The chemicals are also likely to co-occur.

References:

WHO Regional Office for Europe (2019). Towards a tool for assessment of cumulative risks from indoor air pollutants in public settings for children: the first expert consultation. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0020/410780/Indoor-air-pollutants-public-children-first-consultation-report.pdf, accessed 1 November 2019).

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

ESSENTIALS OF HEALTH RISK ASSESSMENT (I)

What it is	Information source
Hazard identification	
<ul style="list-style-type: none"> • Potential of chemicals to cause adverse health • The qualitative description of potential to cause hazard (adverse-effect endpoints, etc.) 	<ul style="list-style-type: none"> • Data from experimental and epidemiological studies • Databases providing available information such as data from agencies, national studies • Scientific publications
Hazard characterization	
<ul style="list-style-type: none"> • The concentration/dose and manner in which the substance causes adverse effects • Safe exposure levels (POD, reference doses/concentrations, NOAEL, LOAEL, BMD) in combination with critical organs/systems and harmful effects 	<ul style="list-style-type: none"> • Data from experimental and epidemiological studies • Databases providing available information such as data from national studies • Scientific publications

References:

WHO (2010). WHO Human health risk assessment toolkit: chemical hazards. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/44458>, accessed 1 November 2019).

DATABASES OF INFORMATION ON CHEMICAL HAZARDS












Numerous institutions have compiled comprehensive and detailed summaries of toxicological information for a wide variety of chemicals essential to conducting risk assessment. Notable among them are the IPCS's online resource INCHEM and the Organisation for Economic Co-operation and Development's (OECD's) online eChemPortal, which are gateways to some sources of internationally peer-reviewed chemical risk assessment information. Other sources of information include the following.

- WHO's Environmental Health Criteria monographs on over 220 chemicals contain detailed summaries of the sources, pathways and routes of exposure.
- The Concise International Chemical Assessment Documents (CICADs) contain information on sources of human exposure; environmental transport, distribution and transformation; environmental levels and human exposure; and information on guidance or guideline values in addition to the hazard characterization of chemicals.
- International Chemical Safety Cards (ICSCs) contain a brief summary of essential information on chemical substances.
- The Screening Information Dataset for High Production Volume Chemicals (SIDS) is an extensive compilation of data on physicochemical properties and toxicity values for the most common chemicals in commerce.
- The IARC monographs include information on single chemicals as well as chemical mixtures in terms of their carcinogenic effects.
- The Hazardous Substances Data Bank (HSDB), maintained by the United States National Library of Medicine, can be accessed through the OECD's eChemPortal. It includes peer-reviewed toxicological data for over 5000 chemicals, including information on human health effects, physicochemical properties, metabolism, toxicology and laboratory methods.
- The European Chemical Substances Information System (ESIS) provides information on the names, synonyms and structures of thousands of chemicals, as well as information on physicochemical properties and toxicity.
- The International Toxicity Estimates for Risk Assessment (ITER) database provides a searchable summary of hazard characterization values and risk-based concentrations derived by WHO as well as national agencies.

continued



References:

WHO (2010). WHO human health risk assessment toolkit: chemical hazards. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/44458>, accessed 1 November 2019).

Links to information resources:

CICADs

<https://www.who.int/ipcs/publications/cicad/en/>

ICSC

https://www.ilo.org/safework/info/publications/WCMS_113134/lang--en/index.htm

HSDB

<https://pubchem.ncbi.nlm.nih.gov/>

ESIS

<https://echa.europa.eu/search-for-chemicals>

ITER

<https://www.tera.org/iter/>

Integrated Risk Information System (IRIS) – United States Environmental Protection Agency (USEPA) database of chemicals

https://cfpub.epa.gov/ncea/iris_drafts/atoz.cfm?list_type=alpha

ESSENTIALS OF HEALTH RISK ASSESSMENT (II)

What it is	Information source
Exposure assessment	
Determination of the quantitative intake of the chemical agent into the organism by different routes (inhalation, ingestion, dermal contact) through various environmental media (air, water, soil, food)	Evaluation of the concentration or quantity of a specific substance: <ul style="list-style-type: none"> • Route and exposure scenario • Frequency of exposure (repeatability) • Duration of exposure • Characteristics of exposed population • Concentration at the point of impact • Exposure factors • Potential doses (intake)
Risk characterization	
Characterization of the risks of chemicals for various sources, scenarios and routes of exposure Identification and analysis of uncertainties in risk assessment. Generalization of the results of the risk assessment and presentation of the findings to risk managers	<ul style="list-style-type: none"> • Exposure estimates for various sources, scenarios and routes of exposure • Reference doses or PODs for hazard • Comparison of exposure and hazard to calculate risk for various sources and routes of intake of chemical substances • Calculation of risks (risk assessment) for combined exposures

References:

WHO (2006). Environmental Health Criteria 237. Principles for evaluating health risks in children associated with exposure to chemicals Geneva: World Health Organization (https://apps.who.int/iris/bitstream/handle/10665/43604/924157237X_eng.pdf?sequence=1&isAllowed=y, accessed 1 November 2019).

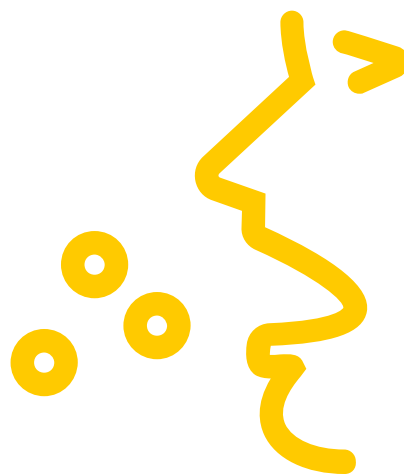
WHO (2010). WHO human health risk assessment toolkit: chemical hazards. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/44458>, accessed 1 November 2019).

EXPOSURE ASSESSMENT (I)

An exposure assessment focuses on three main factors:

1. the relevant routes and pathways of exposure: inhalation, ingestion, dermal;
2. the environmental medium expected to contain the chemical; and
3. the appropriate duration of exposure.

The adjustment of physiological characteristics of population groups and the duration of exposure should be taken into account.



Exposure is defined as the contact of an individual with a pollutant for specific durations of time. For exposure to occur, an individual must be present and must come in contact with a contaminated medium. Exposure usually results in absorbed dose when chemicals enter the body. It is described in terms of the intensity, frequency, and duration of contact. The intensity of contact is typically expressed in terms of the concentration of contaminant per unit mass or volume in the medium to which humans are exposed. Route of exposure is defined as the portal of entry to the body. Pollutants enter the human body in three main ways: by inhalation, ingestion or skin absorption.

Pathway is defined as the course that the contaminant takes from its source to the exposure medium, and then to the portal of entry. For a given source, exposure media and exposure routes can define the pathways.

References:

WHO (2000). Environmental Health Criteria 214: Human exposure assessment. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/42181>, accessed 1 November 2019).

WHO (2006). Environmental Health Criteria 237: Principles for evaluating health risks in children associated with exposure to chemicals. Geneva: WHO (https://apps.who.int/iris/bitstream/handle/10665/43604/924157237X_eng.pdf?sequence=1&isAllowed=y, accessed 1 November 2019).

WHO (2010). WHO human health risk assessment toolkit: chemical hazards. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/44458>, accessed 1 November 2019).

EXPOSURE ASSESSMENT (II)

- Exposure can be measured directly, estimated using models or generalized from existing data.
- Each method requires the determination of time periods relevant to possible adverse health outcomes: if the relevant health hazard is chronic in nature, exposure is likely to be long term.
- For chemicals posing a hazard as a result of cumulative or long-term low-dose exposure, long-term average exposures are most relevant for characterization of adverse effects.
- Assessments of cancer risks are special cases of long-term exposure for which lifetime average exposure is important.

Exposure can be measured directly or indirectly. Direct assessments measure the contact of the person with the chemical in the exposure media over an identifiable period of time. Direct assessments are made through field monitoring studies. In these studies, data are collected on pollutant concentrations in a variety of exposure media (for example, indoor air), activities, and exposure factors so that exposure can be measured or estimated for each person in the study.

Biomarkers do not measure exposure directly, but are an indicator of absorbed dose. A biomarker of exposure is defined as a xenobiotic substance or its metabolite(s) or the product of an inter-action between a xenobiotic agent and some target molecules(s) or cell(s) that is measured within a compartment of an organism and can be related to exposure. Urine, blood, nail, saliva, hair, and faeces are common media collected for biomarker measurements. Currently, there are only a few cases where biomarkers can be used for quantitative exposure assessment.

Models use mathematical expressions to quantify the processes leading to exposure and dose. Models that predict dispersion, fate, transport, and transfer of chemicals are based on physical and chemical principles. Models that describe activities of individuals as they interact with the environment are based on statistical data from observational measurement studies.

Exposure models use available information on concentrations of chemicals in exposure media along with information about when, where, and how individuals might contact the exposure media to estimate exposure.

References:

WHO (2000). Environmental Health Criteria 214: Human exposure assessment. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/42181>, accessed 1 November 2019).

WHO (2006). Environmental Health Criteria 237: Principles for evaluating health risks in children associated with exposure to chemicals. Geneva: World Health Organization (https://apps.who.int/iris/bitstream/handle/10665/43604/924157237X_eng.pdf?sequence=1&isAllowed=y, accessed 1 November 2019).

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

continued

EXPOSURE ASSESSMENT (II)

- Exposure can be measured directly, estimated using models or generalized from existing data.
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- For chemicals posing a hazard as a result of cumulative or long-term low-dose exposure, long-term average exposures are most relevant for characterization of adverse effects.
- Assessments of cancer risks are special cases of long-term exposure for which lifetime average exposure is important.

WHO Regional Office for Europe (2020). Methods for sampling and analysis of chemicals in indoor air. Supplementary document to the screening tool for assessment of health risk from combined exposure to multiple chemicals in indoor air. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/334389>, accessed 11 December 2020).

EXPOSURE ASSESSMENT (III)

Parameter – measurement	How collected	Units
Inhalation exposure ($E_{ime/ma}$)		
$E_{ime/ma} = C_{ame} \times T_{me/ma} \times IR_{ma}$		
C_{ame} – Air concentration (C) in microenvironment (ame)	Measured with active sorbent collection	$\mu\text{g}/\text{m}^3$
$T_{me/ma}$ – Time (T) spent in each microenvironment/ macroactivity (me/ma)	Time–activity diary, questionnaire	h/day
IR_{ma} – Inhalation rate (IR) during each macroactivity (ma)	Estimated from size, age, and activity data collected with diaries and questionnaires using reference values	m^3/h

(WHO, 2006)

References:

WHO (2006). Environmental Health Criteria 237: Principles for evaluating health risks in children associated with exposure to chemicals. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/43604>, accessed 1 November 2019).

CALCULATION OF RISKS

Dose addition

HI, reference dose
(RfD)

$$HI = \sum_{i=1}^n \frac{\text{estimated intake}_i}{RfD_i}$$

Point of departure
index (PODI)

$$PODI = \sum_{i=1}^n \frac{\text{estimated intake}_i}{POD_i}$$

Risk for combined exposures on human health is often characterised by a hazard index (HI) or a point of departure index (PODI). A HI is the sum of the exposures to each of the component compounds of an assessment group divided by their respective reference values. As such, it represents risk-based summation of exposures to individual components, adjusted by their relative hazard. In higher levels of estimation, a PODI can be calculated. A PODI is the sum of exposures divided by the POD for each of the individual components of an assessment group and, as such, represents risk-based summation of exposures to individual components. It overcomes a potential difficulty of the HI, in that it avoids incorporation of different uncertainty factors that may have been used in the derivation of reference values, for reasons unrelated to the common effect. Risk is determined from the magnitude of the index. For comparison, the acceptable HI for a single substance would be 1 or less. The acceptable point of departure index for a single substance would be 0.01 or less, assuming the same default assumptions as are commonly adopted in deriving reference values (i.e., a common uncertainty factor of 100 when based on data from experimental animals).

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO (2010). WHO human health risk assessment toolkit: chemical hazards. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/44458>, accessed 1 November 2019).

TIERS: WHO IPCS FRAMEWORK

	Exposure assessment	Hazards assessment
Tier 0	Summation of semi-quantitative deterministic estimates of exposure	Structure based measure of hazard (i.e., based on toxicity for compounds of similar structure such as the threshold of toxicological concern
Tier 1	Summation of deterministic estimates of exposure to all components of the assessment group based on measurements or modelling	Incorporation of information on potency of individual components; more accurate measures of POD of hazards
Tier 2	Increasing number of measurements; better-defined exposure scenarios; more parameters in models	Refinement of assessment groups and potency estimates through consideration of more specific information on mode of action
Tier 3	Probabilistic in nature, taking into account distribution of intakes and monitoring data	Quantitative information on mode of action, including both kinetic and dynamic aspects

The WHO IPCS Framework includes stepwise integrated and iterative consideration of both exposure and hazard in several tiers of increasingly data-informed analyses. Each tier is more refined (i.e. less conservative and uncertain than the previous one), but additionally labour, modelling and data intensive.

For exposure, the described tiers include examples ranging from simple semi-quantitative estimates of exposure based often on crude surrogates to conservative point estimates based on generic exposure scenarios (Tier 0) to refined estimates incorporating much more monitoring data (probabilistic, where data permit in Tier 3).

Described hazard tiers range from generic thresholds for components within known structural groups of compounds (for example, the threshold of toxicological concern in Tier 0) to more refined estimates of potency (Tiers 1 and 2) to better informed groupings and assessments based on knowledge of mode of action and probabilistic characterization of risk. At any tier, the outcome can be risk management, no further action, generation of additional data or further assessment (i.e., additional refinement in a higher tier).

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

TIERED EXPOSURE IN THE WHO IPCS FRAMEWORK

Tier 0: Simple semiquantitative estimates of exposure

Tier 1: Generic exposure scenarios using conservative point estimates

Tier 2: Refined exposure assessment with increased use of actual measured data

Tier 3: Probabilistic exposure estimates

Case study – Indoor air in schools: measurement (single) or monitoring data

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

TIERED HAZARD IN THE WHO IPCS FRAMEWORK

Tier 0: Structure-based measures of potency

Tier 1: Refined potency based on individual POD, refinement of POD

Tier 2: More refined grouping based on mode of action and potency estimates (for example, relative potency factors)

Tier 3: Physiologically based pharmacokinetic or biologically based dose-response modelling to provide probabilistic estimates of hazard

Case study: Indoor air in schools: POD – reference concentration, NOAEL, LOAEL

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

TIER 0 – WHO IPCS FRAMEWORK

Exposure assessment:

- Crude conservative semiquantitative estimates of summed exposure, modelling or **measurement data or monitoring data**

Hazard assessment:

- Predictive tools, structure–activity relationship (SAR)/quantitative structure–activity relationship (QSAR)
- Same potency as most toxics known
- **Experimental or epidemiological studies**

Risk characterization:

- Health-based guidelines (irrespective of critical effect)
- **HI (based on health-based guidelines)**

The next eight slides provide more information on the WHO IPCS framework tiers and their application for calculating health risks of combined exposure to hazardous chemicals in indoor air (marked blue on the slides).

WHO IPCS framework, Tier 0, Hazard: a conservative very early tier assumption in the absence of information on individual components assumes that all components have the same potency as the most toxic compound known.

WHO IPCS framework, Tier 0, Exposure: In the framework, where the margins between very crude, conservative estimates of exposure and points of departure for hazard are large, simple semi quantitative estimates of summed exposure for the various components of an assessment group may be sufficient as a basis for an early-tier analysis. Semi quantitative estimates require limited data and a few very simple assumptions. Often, combined information on indicators of potential exposure, such as volume, use and/or physicochemical properties, provides measures of relative ranking, which are often quantified crudely based on comparison with more robust quantitative estimates for chemicals with similar profiles. This tier does not necessary require monitoring data.

WHO IPCS framework, Tier 0, Risk characterization: In Tier 0, this is normally based on adjustment for all compounds by the reference value for the most toxic compound. It is considered to be conservative and protective, given the common underlying premise of being based on critical effects occurring at the lowest dose.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

USEPA (2000). Supplementary guidance for conducting health risk assessment of chemical mixtures. Washington, DC: USEPA (<https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=20533>, accessed 1 November 2019).

TIER 0 – SCREENING TOOL FOR COMBINED EXPOSURES IN PUBLIC SETTINGS FOR CHILDREN

Risk characterization: HI

$$HI = \sum_{x=1}^n \frac{\text{measured concentration}_x}{RC_x}$$

Where

x = each substance included in the assessment group, irrespective of their health effects;

RC = reference concentration for inhalation based on critical effect (for example, WHO guidelines for indoor air quality)

The WHO screening tool for assessment of risks of indoor air pollution is based on the WHO IPCS framework for combined exposures. However, it incorporates modified tiers for application in the consideration of combined exposures to pollutants in indoor air in public settings such as schools, kindergartens and day-care centres.

For Tier 0 in the screening tool, risk characterization is based on a HI. An HI is a sum of the exposure to each of the components of the assessment group divided by their respective reference values. As such, it represents a risk-based summation of exposures to individual components, adjusted by their relative hazard.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

TIER 0 – EXAMPLE

CALCULATION OF RISK FROM COMBINED EXPOSURE TO CHEMICALS IN INDOOR AIR

Mixture of 4 substances (A, B, C, D)

Substance	Exposure	Ref _i
A	10mg/m ³	20mg/m ³
B	15mg/m ³	30mg/m ³
C	2mg/m ³	10mg/m ³
D	4mg/m ³	10mg/m ³

$$HI = 10/20 + 15/30 + 2/10 + 4/10 = 1.6$$

HI > 1 – further assessment or risk reduction required

A simplified example of risk calculation is presented on the slide.

TIER 1 – WHO IPCS FRAMEWORK

Exposure assessment:

- Modelling and/or monitoring data
- Generalized, conservative exposure scenarios

Hazard assessment:

- Additional toxicological information for chemicals in the assessment group
- Reference values for each substance (RfD, ADI)
- POD (for example, NOAEL or LOAEL)

Risk characterization:

- Calculation of the HI
- Reference values for each substance (RfD, ADI)
- Calculation of the PODI

WHO IPCS framework, Tier 1, Exposure: For a Tier 1 assessment, summation of deterministic estimates of exposure for all components of the assessment group may suffice as a basis for comparison with a measure of hazard to determine whether further assessment is necessary. Exposure assessment can also base on measured or modelled data, or both.

WHO IPCS framework, Tier 1, Hazard: The analysis is refined by incorporating additional information on the potency of individual chemicals for the common effect, and more accurate measures of points of departure (PODs).

WHO IPCS framework, Risk characterization: This can be undertaken by calculating the HI or PODI. Risk is determined from the magnitude of the index. For comparison, the acceptable HI for a single substance would be 1 or less. The acceptable PODI for a single substance would be 0.01 or less, assuming the same default assumptions as used in deriving the reference values (the common uncertainty factor is 100 when based on data from an experimental study).

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

TIER 1 Level 1 – SCREENING TOOL

Risk characterization:

Effect-based HI

$$HI_{AG} = \sum_{x=1}^n \frac{\text{measured concentration}_x}{RC_x}$$

Where

AGi = an assessment group for each of the groups for priority effects in which the substance is included;

x = each substance included in the assessment group;

RC = reference concentration for inhalation for the relevant substance (for example, WHO guidelines for indoor air quality)

Risk characterization within the screening tool for assessment of combined exposure to chemicals in indoor air:

Tier 1 Level 1 – The tool calculates a HI as indicated above for Tier 0, but with chemicals grouped according to the five selected priority health effects for indoor air pollution in public settings for children:

- effects on the respiratory system
- effects on the nervous system
- effects on the cardiovascular system
- carcinogenicity – IARC Group 1 carcinogens
- eye and respiratory irritation.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

TIER 1 Level 2 – SCREENING TOOL

Risk characterization:

Effect-based adjusted PODI (PODIadj)

$$\text{PODIAdj}_{\text{AG}} = \sum_{x=1}^n \frac{\text{measured concentration}_x}{\text{POD}_{x \text{ adj}}}$$

Where

x = each substance included in the assessment group for priority effects, and

$\text{POD}_{x \text{ adj}}$ = the POD for the relevant priority health effect for substance x adjusted by duration of exposure and an acceptable margin to account for uncertainty

Tier 1 Level 2 – The screening tool calculates an PODIadj for the selected effects of interest. The PODIadj is based on the lowest POD if there are data available for both humans and animals, with the value in animals being normalized to human by a factor of 0.1 to account for interspecies differences. NOAELs are preferred; if only LOAELs are available, the screening tool adjusts the value by a factor of 3. Human variability is taken into account through adjustment of the POD by an additional factor of 10.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

TIER 1 – EXAMPLE

CALCULATION OF RISK FROM COMBINED EXPOSURE TO CHEMICALS IN INDOOR AIR

Mixture of 4 substances (A, B, C, D)

Substance	Exposure	Ref _i	Health effects				POD (NOAEL) (mg/m ³)				TTD value (mg/m ³)			
			I	N	C	R	I	N	C	R	I	N	C	R
A	10mg/m ³	20mg/m ³	✓	✗	✗	✓	2000			4000	20			40
B	15mg/m ³	30mg/m ³	✓	✗	✗	✗	6000			3000	60			30
C	2mg/m ³	10mg/m ³	✓	✗	✓	✗	1000		5000		10		50	30
D	4mg/m ³	10mg/m ³	✗	✓	✓	✗		1000	5000			10	50	

I - immune system N - nervous system C - cardiovascular system R - respiratory system

Tier 1 Level 1: Effect-based HI

$$HI \text{ I} = 10/20 + 15/30 + 2/10 = 1.2$$

$$HI \text{ N} = 4/10 = 0.4$$

$$HI \text{ C} = 2/10 + 4/10 = 0.6$$

$$HI \text{ R} = 10/20 + 15/30 = 1.0$$

Tier 1 Level 2: Effect-based POD_{adj}

$$POD \text{ I} = 10/2000 + 15/6000 + 2/1000 = 0.0095$$

$$POD \text{ N} = 4/1000 = 0.004$$

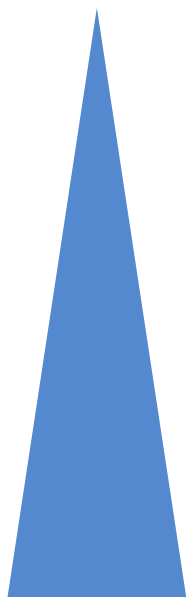
$$POD \text{ C} = 2/5000 + 4/5000 = 0.0012$$

$$POD \text{ R} = 10/4000 + 15/3000 = 0.0075$$

A simplified example of risk calculation is presented on the slide.

SUMMARY

TIERED APPROACH IN SCREENING TOOL



Tier 0 – no grouping by effect. HI summing the ratios of concentrations of each monitored pollutant by their respective acceptable or tolerable concentrations (for example, WHO air quality guideline)

HI > 1, consider additional assessment or remedial measures

Tier 1, Level 1 – grouping by five selected priority health effects; HI_{AGS} summing the ratios of monitored pollutant concentrations by their respective acceptable or tolerable concentrations (for example, WHO air quality guideline) for each of the effect groups

$HI_{AG} > 1$ for any group, consider additional assessment or remedial measures

Tier 1, Level 2 – grouping by five selected priority health effects; Adjusted Point of Departure Indices (PODI_{adj}) summing the ratios of concentrations of monitored pollutants by their points of departure for the relevant effect adjusted to take into account duration and uncertainty for each of the effect groups (non-cancer or non-genotoxic carcinogenicity) or an adequately protective margin (cancer)

PODI_{adj} > 1 for any group, consider additional assessment or remedial measures

The scheme summarizes the methodological approach to the assessment of health risks from combined exposure to hazardous chemicals. It includes three levels of assessment:

- Tier 0 – calculate HI using critical health endpoints without grouping of chemicals according to their adverse-effect endpoints; depending on risk characterization (<1 or >1), complete the assessment or move to another level;
- Tier 1, Level 1 – calculate HI using critical health endpoints with grouping of chemicals according to their adverse-effect endpoints; depending on risk characterization (<1 or >1), complete the assessment or move to another level; and
- Tier 1, Level 2 – calculate of PODI based on NOAEL and LOAEL; characterise risk.

References:

WHO Regional Office for Europe (2021). A screening tool for assessment of health risks from exposure to multiple chemicals in indoor air in public settings for children: methodological approach. Copenhagen: WHO Regional Office for Europe (<https://apps.who.int/iris/handle/10665/341629>, accessed 4 June 2021).

TIER 2 – WHO IPCS FRAMEWORK

Exposure assessment:

- Exposure levels are supplemented by more detailed data (additional monitoring).
- Exposure scenarios are clearly defined and situation-specific.
- Models may include additional parameters.
- This is considered to be more realistic with the inclusion of more data.

Hazard evaluation:

- Review more specific information about the mode of action or other factors which are used for grouping (for example, cholinesterase inhibitors).
- Calculate the TEF or relative potency factor (RPF).

Risk characterization:

- Use equivalent or relative factors (TEF/RPF). The risk is determined by a summation of exposure multiplied by the potency of each component, relative to that for the index component (usually the substance with the most information available).

WHO IPCS framework, Tier 2, Exposure assessment: In Tier 2 assessment, the deterministic estimation of exposure is refined with the incorporation of an increasing number of measured values, and with the continuous monitoring of data. Models can incorporate additional parameters and, although estimates are still considered conservative, they are believed to be more realistic as they incorporate more data.

WHO IPCS framework, Tier 2, Hazard evaluation: The definition of an assessment group may be additionally refined through the consideration of increasingly specific information on mode of action or other factors on which to base grouping (for example, molecular target). In addition, availability of measures of potency for each of the components of the assessment group permits the derivation of relative potency factors. The potency of each compound is expressed as an equivalent of that for an index compound, with the latter being selected on the basis of the most robust and reliable database.

WHO IPCS framework, Tier 2, Risk characterization: Where it is possible to derive relative potency factor, risk is determined by expressing the sum of the relative potency factor-adjusted exposures to all substances in the group as a percentage of the reference values of the index compounds. If combined exposure is 100% or less of the reference value, exposure would be considered acceptable, by analogy with that for a single substance.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

TIER 2 – WHO IPCS FRAMEWORK

Example

Compound	ADI (µg/kg/d)	RPF
CAG A	4	2.50
CAG B	45	0.22
CAG C	4	2.50
CAG D	24	0.42
CAG E	80	--
CAG F	25	0.40
CAG G	50	0.20
CAG H	15	0.67
CAG I	10	1.00
CAG J	50	--
CAG K	20	0.50

Chemical assessment group (CAG) E and CAG J appeared to have another mode of action and can thus be removed from the common assessment group.

$$\sum_{x=1}^n \text{measured concentration}_x \times RPF_x$$

Where

x = each substance included in the assessment group

The toxic equivalency factor (TEF)/toxic equivalent (TEQ) concept has been developed to facilitate risk assessment and regulatory control. While the initial and current set of TEFs only apply to dioxins and dioxin-like chemicals (DLCs), the concept can theoretically be applied to any group of chemicals satisfying the extensive similarity criteria used with dioxins, primarily that the main mechanism of action is shared across the group. Thus far, only the DLCs have had such a high degree of evidence of toxicological similarity.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

Van de Berg M, Birnbaum LS, Denison M, De Vito M, Farland W, Feeley M et al. (2006). The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicol Sci.* 93(2):223–41. doi:10.1093/toxsci/kfl055.

TIER 3 – WHO IPCS FRAMEWORK

Exposure assessment:

- This includes representative information about the exposure levels for all the considered exposure scenarios in evaluated populations.
- This could be based on multiple sources of chemical substances.

Hazard evaluation:

- Where available, use verified pharmacokinetic models and biologically based dose–response models for obtaining a probabilistic evaluation of the hazard, which enables the assessment of kinetic and dynamic variability.

Risk characterization:

- Conduct a probabilistic assessment to determine the percentile of the population that exceeds reference (safe) exposure levels.

In Tier 3 assessment, estimates of exposure are probabilistic in nature, taking into account the distribution of exposure factors or exposure data. This approach requires representative information of exposure for the scenarios of interest for different users and across populations. Models at this level of complexity often include multiple-source exposure.

Tier 3 assessment incorporates increasingly refined information on mode of action, including both kinetic and dynamic aspects. These can include both physiologically, pharmacokinetic and biologically based dose-response models, which may permit probabilistic estimates of hazard and characterization of some aspects of kinetic and dynamic variability and uncertainty.

In probabilistic assessment, risk can be estimated as the percentile of the population exceeding the reference value, as the maximum exceedance of the reference value, or as the percentage of the population at or below the reference value for a given percentile of distribution (for example, the 99.9th percentile). Interpretation requires agreement as to what percentile is considered acceptable by the programme manager.

References:

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Raaij MV, Vickers C (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regul Toxicol Pharmacol.* 60(2):S1–14. doi:10.1016/j.yrtph.2011.03.010.

INTERPRETATION OF RESULTS (I)

- The combined effects of multiple chemicals address the risk of adverse effects on critical organs and systems.
- Even if the risk level of one substance does not exceed the acceptable level, the combined exposure to substances that affect the same system can cause harm.

INTERPRETATION OF RESULTS (II)

All assumptions and uncertainties should be clearly messaged to the risk manager so that they can make an informed decision on risk prevention measures.

- Confirm that specific and top-priority chemicals are included in the assessment and that the assessment group is formed applying relevant methodological principles.
- Identify adverse effect endpoints based on analysis of the toxicological information and epidemiological studies and data.
- Obtain quantitative information on the toxicity of substances from recognized databases and/or from the best available studies.
- Collect exposure data using accepted methods and models.
- Tier assessment to conserve resources and focus risk reduction measures, where required.



RISK COMMUNICATION

STRUCTURE OF THIS MODULE

- What is risk communication?
- Principles for communicating risks and main challenges –good communication practices
- Why and to whom to communicate what information, and how: planning a risk communication strategy
- Annex: examples of key messages to different target groups

OBJECTIVES OF THIS MODULE

- Share knowledge in risk communication.
- Discuss and apply a communication methodology in the context of indoor air pollution.
- Identify risk communication challenges and understand how to address them.
- Describe characteristics and principles for effective risk communication.
- Prepare audience-oriented key messages.

Risk communication is an integral component of public health risk management. It focuses on dialogue with those affected and concerned, and strives to ensure that communication strategies are evidence-based. The main goal of this module is to assist public-health and health-care professionals who are not risk communication experts in their task of communicating with different professionals and groups of the public.

GOALS OF RISK COMMUNICATION

- Raising awareness about indoor air pollution in public buildings and its health effects by providing accurate and comprehensible information in clear and simple messages
- Disseminating knowledge on risk-reduction measures
- Establishing relationships to promote risk-reduction measures
- Encouraging protective behaviour and actions to reduce risks
- Involving all stakeholders, including decision-makers
- Facilitating the development of risk-reduction policies

Health communication related to indoor air quality cannot be limited to disseminating knowledge; the real goal is to achieve behavioural change that leads to cleaner indoor air. One way to do this is to communicate risks to stakeholders in a timely, clear and understandable way – in other words, to use communication tools as a means of prevention. This training material follows this principle. Proper risk management can protect participants from many negative consequences, which can often be expressed in monetary terms. Thus, it is worthwhile and necessary to invest resources in the implementation of risk communication.

References:

WHO (2015). Effective communications. Participant handbook: communications training programme for WHO staff. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/249241>), accessed 4 December 2019).

WHAT IS COMMUNICATION?

Sharing concerns and opinions



Building mutual understanding



Exchanging information



Transferring knowledge



Fostering social connectivity



Engaging in dialogue with the community

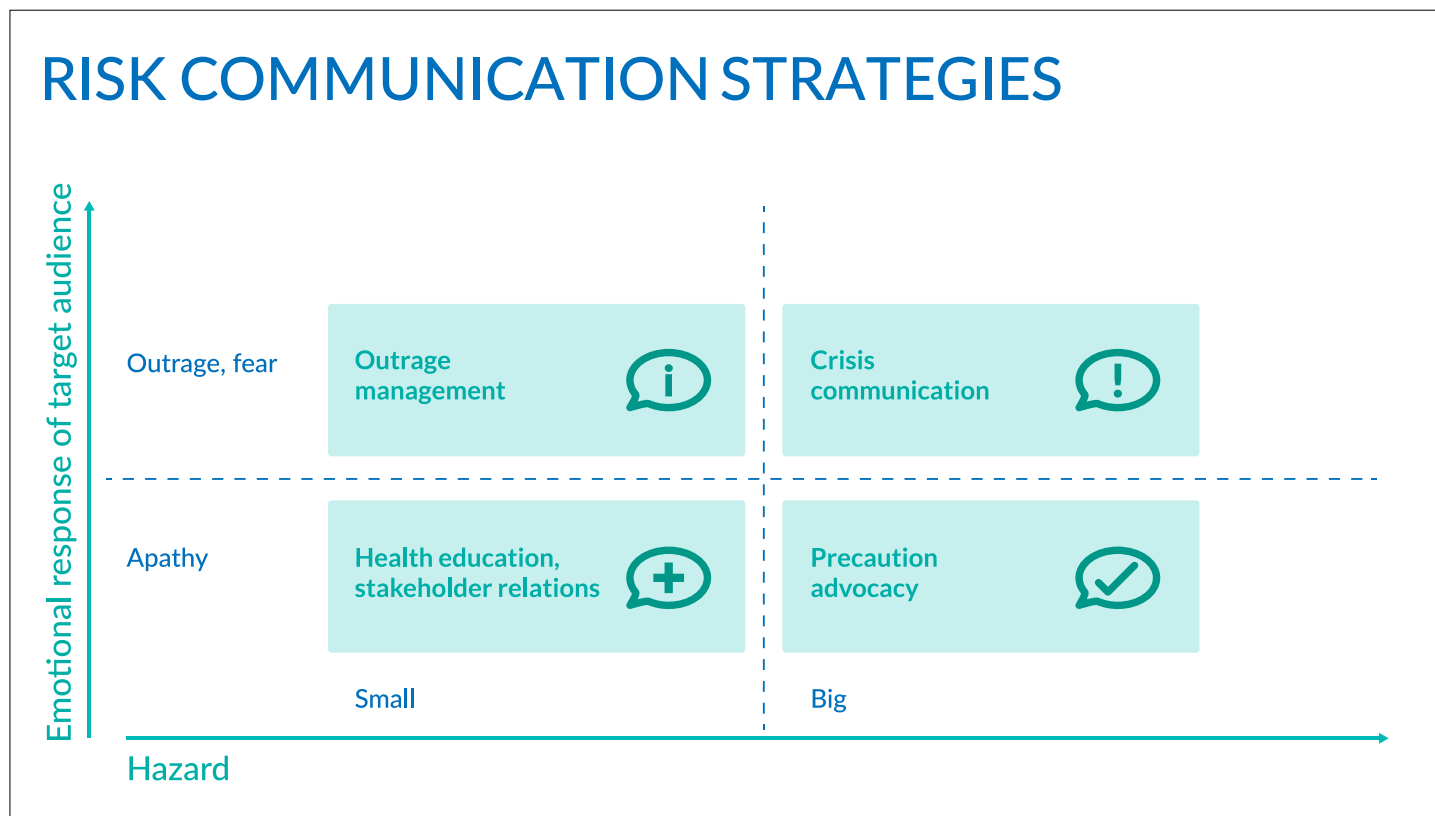


Communication involves exchanging information with the aim of informing people, engaging in dialogue with them and/or influencing their knowledge, attitudes and behaviour. The only way you, the risk communicator, can be sure you are doing your job effectively is by soliciting feedback from those you are communicating with – that is, by fostering a two-way exchange of information. Effective communication generates dialogue that satisfies both the sender and the receiver of information.

References:

Ágnes J. Vezetés és kommunikáció [Leadership and communication] (2013). Budapest: National University of Public Service (in Hungarian) (https://www.researchgate.net/publication/325723284_Vezetes_es_kommunikacio_Leaders_Communication, accessed 4 December 2019).

RISK COMMUNICATION STRATEGIES



This is a model proposed by Peter Sandman, a preeminent risk communication expert. It analyses risk perception based on the severity of the hazard as perceived by public health experts across the horizontal axis, and the degree of emotion expressed by the affected population – fear, anger, concern, outrage and other emotions – along the vertical axis. Based on your analysis of where the risk perception lies in the following matrix, you will use one of the four risk communications strategies described here.

- Outrage management: how to calm people who are excessively frightened or angry about a small hazard
- Crisis communication: how to protect and defend an individual, company or organization facing a public challenge to its reputation
- Health education and stakeholder relations (community surveillance): how to use communication surveillance to identify and address outrage early on
- Precautionary advice: how to behave to prevent any accident/crisis.

References:

Bundy J, Pfarrer MD, Short CE, Coombs WT (2017). Crises and crisis management: integration, interpretation and research development. *Journal of Management*. 43(6):1661–92. doi:10.1177/0149206316680030.

Sandman P (2014). Outrage management (low hazard, high outrage) [website]. Brooklyn: Peter Sandman Risk Communication (<https://www.psandman.com/index-OM.htm>, accessed 9 November 2019).

WHO (2004). Outbreak communication. Best practices for communicating with the public during an outbreak. Geneva: WHO (https://www.who.int/csr/resources/publications/WHO_CDS_2005_32web.pdf, accessed 9 November 2019).

WHO (2015). Effective communications. Participant handbook: communications training programme for WHO staff. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/249241>, accessed 4 December 2019).

FACTORS AFFECTING PERCEPTION OF RISK

Higher concern for substances/events

- Human-made (radiation from nuclear power)
- Voluntary (sun tanning, smoking)
- Dreadful (incurable diseases)
- Unfamiliar/new/exotic (COVID-19 pandemic)
- Catastrophic/acute (plane crash)
- Out of control (air crashes)
- Direct benefits
- Known victims
- Affect me
- Inescapable

Lower concern for substances/events

- Natural (sun radiation)
- Involuntary (pesticide pollution)
- Non dreadful (curable diseases)
- Familiar/known (seasonal influenza)
- Chronic (air pollution)
- In control (road crashes)
- Indirect benefits
- Unknown victims
- Affect “them”
- Preventable

One aspect of understanding comparative risks is understanding how people perceive risks. The nature of a risk often leads to different perceptions of the risk by the people affected. Often, several factors (see below) can be involved simultaneously. For example, fear of SARS-CoV-2 virus is high because awareness is high, it's new, and a lot of uncertainty remains. However, fear of particulate air pollution remains low (compared with what scientists say is the actual risk) because it's chronic and awareness is still low. Some people fear a risk more than other people do. Parents fear child abductions more than nonparents do. Risk perception is changing over time. Surveys have found that the following pairs of characteristics of a situation generally affect risk perception.

Human-made vs natural: We are less afraid if the risk is natural (radiation from the sun) and more afraid if it's human-made (radiation from nuclear power).

Voluntary vs involuntary exposure: People feel much less at risk when the choice is theirs. Those who do not use mobile telephones may perceive the risk as high from the relatively low radio frequency fields emitted from mobile telephone base stations. However, mobile telephone users generally perceive as low the risk from the much more intense radio frequency fields from their voluntarily chosen handsets.

Dreaded vs not-dreaded outcomes: Some diseases and health conditions, such as cancer, or severe and lingering pain and disability, are more feared than others. Thus, even a small possibility of cancer, especially in children, receives significant public attention.

Familiar vs unfamiliar: Familiarity with a given technology or a situation helps reduce the level of the perceived risk. The perceived risk increases when the technology or situations new, unfamiliar, or hard to comprehend. Perception about the level of risk can be significantly increased if there is an incomplete scientific understanding about potential health effects from a particular situation or technology.

Catastrophic/acute vs chronic: We tend to be more afraid of things that can kill a lot of us, suddenly and violently and all in one place, such as a plane crash, than things like heart disease, which causes hundreds of thousands more deaths, but one at a time, over time, and not all in the same place.

Personal control vs lack of control over a situation: If a person feels as though he or she can control the outcome of a hazard, that individual is less likely to be afraid.

continued

FACTORS AFFECTING PERCEPTION OF RISK	
<p>Higher concern for substances/events</p> <ul style="list-style-type: none"> • Human-made (radiation from nuclear power) • Voluntary (sun tanning, smoking) • Dreadful (incurable diseases) • Unfamiliar/new/exotic (COVID-19 pandemic) • Catastrophic/acute (plane crash) • Out of control (air crashes) • Direct benefits • Known victims • Affect me • Inescapable 	<p>Lower concern for substances/events</p> <ul style="list-style-type: none"> • Natural (sun radiation) • Involuntary (pesticide pollution) • Non dreadful (curable diseases) • Familiar/known (seasonal influenza) • Chronic (air pollution) • In control (road crashes) • Indirect benefits • Unknown victims • Affect "them" • Preventable

Direct vs indirect benefits: If people are exposed to radio frequency fields from mobile telephone base stations, but do not have a mobile telephone, or if they are exposed to the electric and magnetic fields from a high voltage transmission line that does not provide power to their community, they may not perceive any direct benefit from the installation and are less likely to accept the associated risk.

A known victim vs unknown victim: A risk that is made real by a specific victim, becomes more frightening, even though the actual risk may be no greater than it was before it was personified by this victim.

Does it affect me? We don't perceive risk to "them", to society as fearfully as we do risks to ourselves. This explains the desire for zero risk. A person doesn't care if the risk of cancer from pesticides residues on food is one in a million if he or she could be that one.

References:

Ropeik D (2002). Understanding factors of risk perception. Cambridge: Nieman Reports (<https://niemanreports.org/articles/understanding-factors-of-risk-perception/>, accessed 27 July 2020).

WHO (2002). Establishing a dialogue on risks from electromagnetic fields. Geneva: World Health Organization (https://www.who.int/peh-emf/publications/en/EMF_Risk_ALL.pdf, accessed 27 July 2020).

PRINCIPLES OF RISK COMMUNICATION (I)

- Build, maintain or restore trust.
- Base communication on scientific evidence.
- Maintain integrity of information.
- Be clear.
- Be consistent.
- Be transparent.
- Consider your purpose and adapt messages to audience needs and expectations.
- Be prepared for objections and keep confidence.
- Communicate benefits.

Provide facts confirming that the situation can be changed and communicate what is needed to make that happen.



(WHO, 2017)

There are several key principles to consider when forming risk communication messages.

- **Build, maintain or restore trust:** The overriding goal for communication is to communicate with the public in ways that build, maintain or restore trust. This is true across cultures, political systems and levels of country development. Maintaining the public's trust requires transparency: communication that is candid, easily understood, complete and factually accurate, and that also discloses assumptions, methodologies and uncertainties. Transparency provides many benefits. It demonstrates, for example, that even in the face of uncertainties and unknowns, public health experts are systematically seeking answers. In today's globalized, highly connected world, information is almost impossible to keep hidden from the public. People are more likely to overestimate risk if information is withheld, and evidence shows that the longer officials withhold worrisome information, the more frightening the information will seem when it is revealed – especially if done so by an outside source. To prevent rumours and misinformation and to frame the event effectively, announce it as early as possible. Base all of your facts on evidence. Finally, remember that understanding the public is critical to effective communication. It is difficult to change pre-existing beliefs unless they are explicitly addressed, and nearly impossible to design successful messages that bridge the gap between experts and the public without knowing what the public thinks.
- **Maintain integrity of information:** Acknowledge uncertainty, note limitations of the data, discuss assumptions, and distinguish between results that are supported by analysis and those that are not. Keep your key message simple, straightforward and concise, and deliver it in the language of the target group. Avoid foreign or scientific words. What is important to a health expert is not necessarily important to other members of society. Communicate different messages to the public, to professionals and to decision-makers, adapting them to each group's understanding of the problem. Maintain consistency but not at the expense of accuracy. If new information is not consistent with what you have said in the past, acknowledge the change or previous mistakes and then explain the situation as it stands.
- **Be clear, transparent and consistent:** Clarity means communicating in a direct, simple and understandable way. It involves avoiding jargon and discussing the situation without technical or scientific terms unless it is necessary for the audience. As mentioned above, transparency means disclosing assumptions, methodologies and uncertainties.

continued



- **Respect the audience's concerns:** Acknowledge the audience's concerns and/or issues and provide them with opportunities to collaborate or provide feedback when possible. Answer questions and provide options. If you say you will get back to someone, make sure you follow up. Remember your audience may have important information that you lack, or important concerns of which you are unaware.

References:

O'Malley P, Rainford J, Thompson A (2009). Transparency during public health emergencies: from rhetoric to reality. *Bull World Health Organ.* 87(8):614–18. doi:10.2471/BLT.08.056689.

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

PRINCIPLES OF RISKS COMMUNICATION (II)

- Control your (body) language.
- Determine the target audience.
- Become familiar with the audience – collect some information about their background situation.
- Listen to the audience.
- Provide new and interesting facts explicitly related to the topic or close to it.
- Be focused but friendly.
- Share your personal experience if possible.

Communication is more than just written and spoken language – it also includes gestures, mimicry, tone, posture, etc. We are all engaging in and interpreting these elements in our daily lives as we seek to be understood by others and to understand them.

References:

O'Malley P, Rainford J, Thompson A (2009). Transparency during public health emergencies: from rhetoric to reality. *Bull World Health Organ.* 87(8):614–18. doi:10.2471/BLT.08.056689.

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

BUT BE CAREFUL ...

Make sure to inform your partners first. Establish contact with them in advance, and have a common strategy.

When information is incomplete, state any uncertainties clearly, for example:

“This is what we know at the moment. Information may change as the investigation continues.”

Scientists and experts
speak like this



Main message



But we listen
like this

The key message is always simple, straightforward, concise and delivered in the language of the target group. Remember that what is important to a professional expert is not necessarily important to the public.

References:

Lundgren RE, McMakin AH (2018). Risk communication: a handbook for communicating environmental, safety, and health risk. Sixth edition. New Jersey: Wiley-IEEE Press.

SHAPING COMMUNICATION MESSAGES

1. Keep it simple and concise (up to three key messages in short sentences).
2. Ensure that content is evidence-based, credible and consistent.
3. Provide only facts that have been verified and cleared.
4. Use clear, nontechnical language free of jargon and acronyms.
5. Give people something to do to protect their health.
6. Acknowledge uncertainty and mistakes.
7. Do not over-reassure or minimize risk.
8. Explain how the issues affect people and their lives.
9. Make extensive use of analogies and human stories.
10. Provide a conclusion.

To engage an audience, risk communicators need to understand motivation – their own as well as that of others. If this element is neglected, it is unlikely that enough people will lend the necessary support. Frequently, which facts are presented or what argument is made matters less than the terms in which a case is made – how the issue is framed, whether it meets the psychological needs of the audience, and whether factors such as the channel, messenger or context are right. Effective campaigning rarely results from simply educating people with the aim of changing their minds; more often, it results from identifying key audiences for change, finding out what motivates them and tailoring the message accordingly.

Effective risk communication messages include information about what the public can do to make themselves safer. This affords people a sense of control over their own health and safety, which in turn allows them to respond more reasonably to risk. Communication about personal preventive measures is particularly useful as it empowers the public to take some responsibility for their health. Key principles include the following.

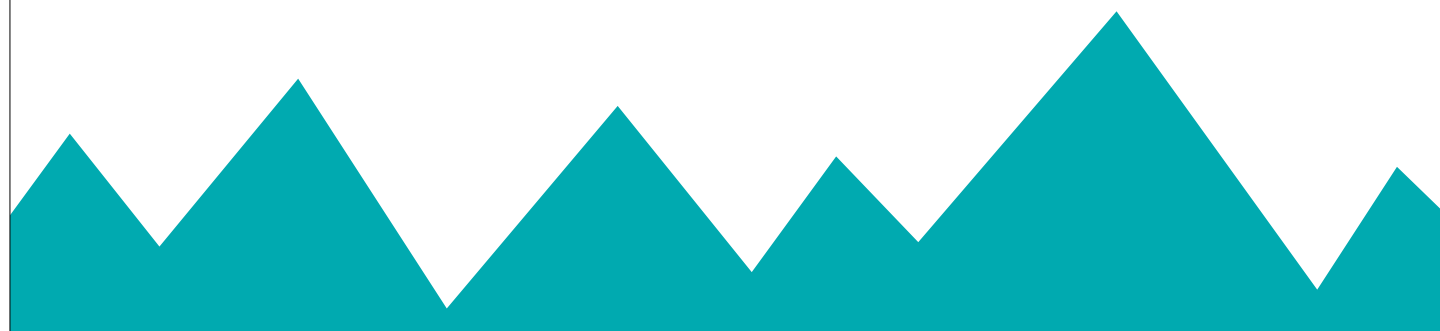
- Keep it simple and concise: Ideally, communicate a single main point; if this is not possible, communicate two or three points at the most. It is better to leave people with a clear idea of one message than to confuse or overwhelm them with too many.
- Use appropriate language: Always pretest messages with representatives of the target audience to ensure that the message sent is the one received.
- Ensure that content is evidence-based and credible: Make the format of your content consistent and ensure that a credible messenger is delivering it. Maintain this coherence throughout the campaign with consistent factsheets, backgrounders, position statements, etc.
- Use an appropriate tone: Ensure that your tone is consistent with the message you are communicating.
- Give people something to do: Offer a message that not only persuades through valid data and sound logic, but also describes action(s) that the audience is encouraged to take.

References:

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

CHALLENGES

1. Lack of clarity about responsibility for communicating (information sources)
2. Existing communication strategies that lack critical information, including risk-mitigation behaviours and long-term health impacts (information quality)
3. Existing communication that fails to reach vulnerable populations (information reach)
4. Personal bias (an influence that prevents risk communication from being completely clear, accurate and impartial)



References:

Ramirez AS, Ramondt S, Van Bogart K, Perez-Zuniga R (2019). Public awareness of air pollution and health threats: challenges and opportunities for communication strategies to improve environmental health literacy. *J Health Commun.* 24(1):75–83. doi:10.1080/10810730.2019.1574320.

Sharp Cloud (2018). Common challenges in risk communication [website]. London: Sharp Cloud (<https://www.sharpcloud.com/blog/common-challenges-in-risk-communication>, accessed 4 December 2019).

DEVELOPING A STRATEGIC PLAN

Objectives:

What do you want to achieve? (aim for a SOCO – a single overarching communications outcome)

Target audiences:

Who do you need to address?
(the public, the media, other stakeholders, etc.)

Channels:

Which channels are the most suitable? (print media, radio, television, health professionals, promotion materials, etc.)

Messages:

What kind of messages most effectively influence your audience(s)?

Partners:

What other actors can become allies?
(nongovernmental organizations, other sectors, other agencies, etc.)

Resources:

How much can you invest?
(in both human and economic resources)

Timeframe:

What is a suitable timeframe for your strategy?

Evaluation tools:

What instruments can you use to evaluate your campaign?

When developing system-level advocacy plans, identifying goals is of the utmost importance. Many advocacy campaigns aiming to change social norms have long-term delivery horizons. Progress towards this vision of the future is a matter of small steps – a series of objectives for the short term. Some of these may not go as planned, but overall progress is in the right direction.

Your campaign objectives should be SMART:

- **S**pecific (specifying what you want to achieve)
- **M**easurable (showing if the objectives are being met)
- **A**chievable (attainable)
- **R**ealistic (achievable with the resources you have)
- **T**ime-bound (achieved within a set timescale/deadline).

You can also set explicit objectives for the process of advocacy itself, such as:

- ensuring that an issue is discussed publicly and politically;
- discussing an issue in ways that are more conducive to the advancement of public health policies and funding; and
- discrediting the opponents of public health objectives.

References:

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

A RISK COMMUNICATION STRATEGY SHOULD BE DEVELOPED BEFORE STARTING THE CAMPAIGN



WHY

WHO

WHAT

HOW

The main purpose of your risk communication strategy is to enable your audience to make informed decisions in order to protect themselves and other people. Answer the following four questions to launch an effective strategy:

- Why do I want to communicate?
- Who has to know what?
- What is the change I want to see as a result of my communication?
- How do I communicate what needs to be shared?

References:

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

THE SOCO PRINCIPLE TO IDENTIFY A RISK COMMUNICATION GOAL

Single

Overarching

Communications

Outcome

What is a SOCO?

- This is the change you want to see in your audience.
- It is the fixed point you keep in mind during communications.
- Risk communicators develop messages to achieve the SOCO only after considering the needs and nature of the target audience(s).

The single overarching communication outcome (SOCO) is the main message to your target audience through which you hope to achieve the communication aim. Ask yourself: “What is the one message I want the audience to take away from this interview/report?” or “What is the one message or action someone needs to understand?” A good SOCO should be objective, concise and precise. A SOCO is especially important when communicating with the media.

The United States Centers for Disease Control and Prevention (CDC) media relations office developed the concept of the SOCO as a key part of the preparation of a communication process. The CDC advises that risk communicators develop their SOCO by answering the four questions explored in previous slides: why, who, what and how.

Note that the SOCO is not the *objective* of the communication process (which usually reflects your perspective), but rather an *outcome* expressed from the perspective of the audience. It must explicitly express the desired change, and it must be time-limited, realistic and achievable. Together with other interventions (programmatic activities, advocacy, etc.), it must contribute to a larger programme goal or objective. The SOCO will be your fixed point of focus during all communications. Develop the messages to achieve the SOCO only after considering the needs and nature of your target audience(s).

In summary, every communication process has a basis – that is, it has content. In epidemiology, this content is usually focused on a study along with certain elements, for example, the public health problem that the study addresses, the study objective, the methods of the study, the results of the study, recommendations based on the study, etc. Beyond this content, the communication process includes a communication aim, a target audience and a SOCO.

References:

Field Epidemiology Manual Wiki (2019). SOCO (single overriding communication message) [website]. Solna: European Centre for Disease Prevention and Control ([https://wiki.ecdc.europa.eu/fem/Pages/SOCO%20\(single%20over-riding%20communications%20objective\).aspx](https://wiki.ecdc.europa.eu/fem/Pages/SOCO%20(single%20over-riding%20communications%20objective).aspx), accessed 9 November 2019).

WHO (2015). Effective communications. Participant handbook: communications training programme for WHO staff. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/249241>, accessed 4 December 2019).

SOCO FOR COMMUNICATING AN INDOOR AIR QUALITY RISK: EXAMPLE OF SETTING A GOAL

My goal is to promote the improvement of indoor air quality and ensure the implementation of risk-reduction measures.

The change that I want to see in my audience is a change in behaviour – for them to take action to protect children in public buildings from exposure to hazardous chemicals in indoor air.

I want the local government and school administration to commit to procuring low-emission goods for schools, kindergartens and day-care centres, and to allocate sufficient financial resources for this.

I want people to actively participate in prioritizing actions, allocating resources and collecting external funds to improve indoor air quality and children's health.

An example of setting a goal based on SOCO principle for communicating an indoor air quality risk is provided on the slide.

AUDIENCE-FOCUSED COMMUNICATION

- This places a specific focus on the needs of different target groups.
- The communication strategy is based on information about the intended target group.
- Information needs to be understandable by any audience.

To be effective, the message must be targeted at specific groups and delivered in different ways using appropriate channels.

In risk communication, the target will rarely be a single audience. As such, messages must be tailored to different audiences that are likely to have different interests, values, and levels of education and understanding. Information about indoor air quality can and will be used by different people for different purposes. It is useful to think about who needs what information, and when and how this information can be delivered. Asking these questions helps in devising an effective information supply. Presenting everything to everyone is inefficient (costly) and ineffective (too much and/or inappropriate information leads to inaction).

References:

Lundgren RE, McMakin AH (2018). Risk communication: a handbook for communicating environmental, safety, and health risk. Sixth edition. New Jersey: Wiley-IEEE Press.

TARGET GROUPS



Children



Parents



Teachers



School managers



Health-care
providers,
health
professionals



Government
authorities,
policy-makers

Who are we trying to reach? Indoor air pollution remains one of most serious health risks, but the general public is not our target audience. If we try to reach everyone, we will end up reaching no one. We need to narrow our target audience. Who is directly affected and who can do the most to solve the problem?

- Children: Inform children about how to behave, how to treat the school environment carefully, and how repairs and renovations can cause pollution and dust.
- Parents: Inform parents about how to prevent indoor air pollution and how they can influence its quality.
- Teachers: Remember that teachers play a key role in the lives and therefore the health of children. Inform teachers so that they can inform parents and children, and ensure that they are connected to health-care professionals so that they can report health risks if necessary.
- School managers: Remind school managers that they have a responsibility to provide a school environment that is safe and conducive to learning.
- Health-care professionals: Equip and support health-care professionals to diagnose and treat health issues related to indoor air quality, and to inform parents about the adverse health effects of indoor air quality in households, schools and kindergartens.
- Public-health professionals: Help these professionals to improve their understanding of pollutant risks, including the risks arising from mixtures of hazardous chemicals in indoor air.
- Local governments: Inform governments using a cost-effectiveness approach that links childhood diseases to school environments.
- Policy-makers: Advocate for stronger laws to protect children's health in public buildings.

References:

Lundgren RE, McMakin AH (2018). Risk communication: a handbook for communicating environmental, safety, and health risk. Sixth edition. New Jersey: Wiley-IEEE Press.

WHO (2017). Inheriting a sustainable world? Atlas on children's health and the environment. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/254677>, accessed 9 November 2019).

WHO (2018). Air pollution and child health: prescribing clean air. Geneva: World Health Organization (https://www.who.int/ceh/publications/Advance-copy-Oct24_18150_Air-Pollution-and-Child-Health-merged-compressed.pdf?ua=1, accessed 9 November 2019).

POTENTIAL GROUPS IN THE AUDIENCE (I)



Once you have defined and categorized your audiences, you can start to think about strategies. Decide which individuals or groups you should target to achieve your SOCO. Think of what needs to be done at what time. This is the beginning of your communications strategy.

People have their own psychological characteristics that can significantly influence a communication campaign – both to make it successful or to make it fail. In terms of risk communication, people from all target groups can be divided into four categories according to their behaviour: blockers, champions, avoiders and silent boosters.

References:

WHO (2015). Effective communications. Participant handbook: communications training programme for WHO staff. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/249241>, accessed 4 December 2019).

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

POTENTIAL GROUPS IN THE AUDIENCE (II)



The table provides advice on how to get them all on your side. Remember to involve champions and be prepared to work with blockers.

References:

WHO (2015). Effective communications. Participant handbook: communications training programme for WHO staff. Geneva: World Health Organization (<https://apps.who.int/iris/bitstream/handle/10665/249241/9789241509466-eng.pdf?sequence=3&isAllowed=y>, accessed 4 December 2019).

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

PERSONALIZE YOUR MESSAGES

Connect emotionally with your audience's values and concerns.

Research what the target audience perceives and believes.

Understand their perceptions of risk and their pre-existing knowledge, attitudes, practices and beliefs.

This will enable you to tailor messages and information.

Messages must be clear, concise and consistent, and serve as a call to action.

Powerful messages include details about the impact of indoor air quality on daily life and society. It is very important to craft messages with this in mind in order to empower your target audience. To connect emotionally with them, you must be familiar with their unique needs and concerns. Targeting messages to different audiences is key to getting your overall message heard by diverse people. Journalists and members of civil society take interest in and begin to listen to different topics and issues. Considering these and revealing related aspects of your issue will increase your chances of reaching a broad audience.

It is also important to understand how your audience prefers to receive information and to present your message in different ways. Use simple, clear language. Remember that scientific studies can be difficult to understand for the average citizen who does not have a health background. Try to reword the evidence in language that is easily understood by everybody. This preparatory work will result in a far higher success rate.

References:

European Union Partnership on Air Quality (2019). Toolkit. Communicating on air quality and health. Inspiring practices, challenges and tips. Brussels: European Union (https://ec.europa.eu/futurium/en/system/files/ged/181008_final_toolkit_on_communicating_on_air_quality_and_health_heal.pdf, accessed 9 November 2019).

Land S, Fewtrell L, Bartram J (2001). Risk communication. In: Fewtrell L, Bartram J, editors (2001). Water quality: guidelines, standards and health. London: IWA Publishing: 317–32 (https://www.who.int/water_sanitation_health/dwq/iwachap14.pdf?ua=1, accessed 9 November 2019).

WHAT DO YOU NEED TO KNOW ABOUT INDOOR AIR QUALITY? WHICH INFORMATION CAN YOU COMMUNICATE?

People's health

Good practices
for cleaner air



Examples of topics to consider when communicating about indoor air quality include:

- air quality as a health determinant;
- places where indoor exposures to air pollutants may occur;
- sources of pollutants in indoor air from both outside and inside;
- characteristics of pollutants in indoor air;
- children's health and why children are more vulnerable to exposure to chemical pollutants;
- risk prevention/reduction measures;
- how to keep indoor air clean; and
- good practices.

There are many sources of relevant information on these topics, including the online sources from WHO.

References:

WHO (2021). Air pollution [website]. Geneva: World Health Organization (https://www.who.int/health-topics/air-pollution#tab=tab_3).

SOURCES OF INFORMATION

Use only reliable, factual and credible sources, such as:

- scientific publications
- reports from international organizations
- statistical information and data sets
- publications from other countries
- ... and many more.



Risk communicators need to compose messages that come from reliable, published sources that are factual and credible. Publications reviewed by scientists and other experts are often the most reliable sources available. However, studies may be outdated and their findings may have been invalidated by current research findings; it is therefore important to pay attention to the most up-to-date studies.

References:

Lundgren RE, McMakin AH (2018). Risk communication: a handbook for communicating environmental, safety, and health risk. Sixth edition. New Jersey: Wiley-IEEE Press.

COMMUNICATION CHANNELS

- Websites
(specialized sites and publications, etc.)
- Social media
(Facebook, Twitter, Instagram, etc.)
- Traditional media
(television, radio, printed press, etc.)
- Information sessions
(events, etc.)
- Bilateral and multilateral meetings
- Group and community meetings
- Individual conversations
- Partners and stakeholders
(both internal and external)
- Classroom events

Effective mapping of communications channels will ensure that your messages are disseminated through multiple channels so that audiences receive the information, advice and guidance several times from a range of sources. Communicators understand that channels tend to fall into three main categories.

Mass media. These channels have broad reach and include television, radio, newspapers, magazines, outdoor and transit advertising, direct mail and websites. Placement through these channels may be free through public service announcements (PSA) or may incur a cost if placement on certain platforms or at specific times is important.

Organization and community. These channels reach specific groups of individuals based on geography (for example, a specific village) or a common interest, such as occupational status. Channels may include community-based media, such as local radio talk shows, organization newsletters; community-based activities, such as health fairs; and meetings at schools, workplaces and houses of worship.

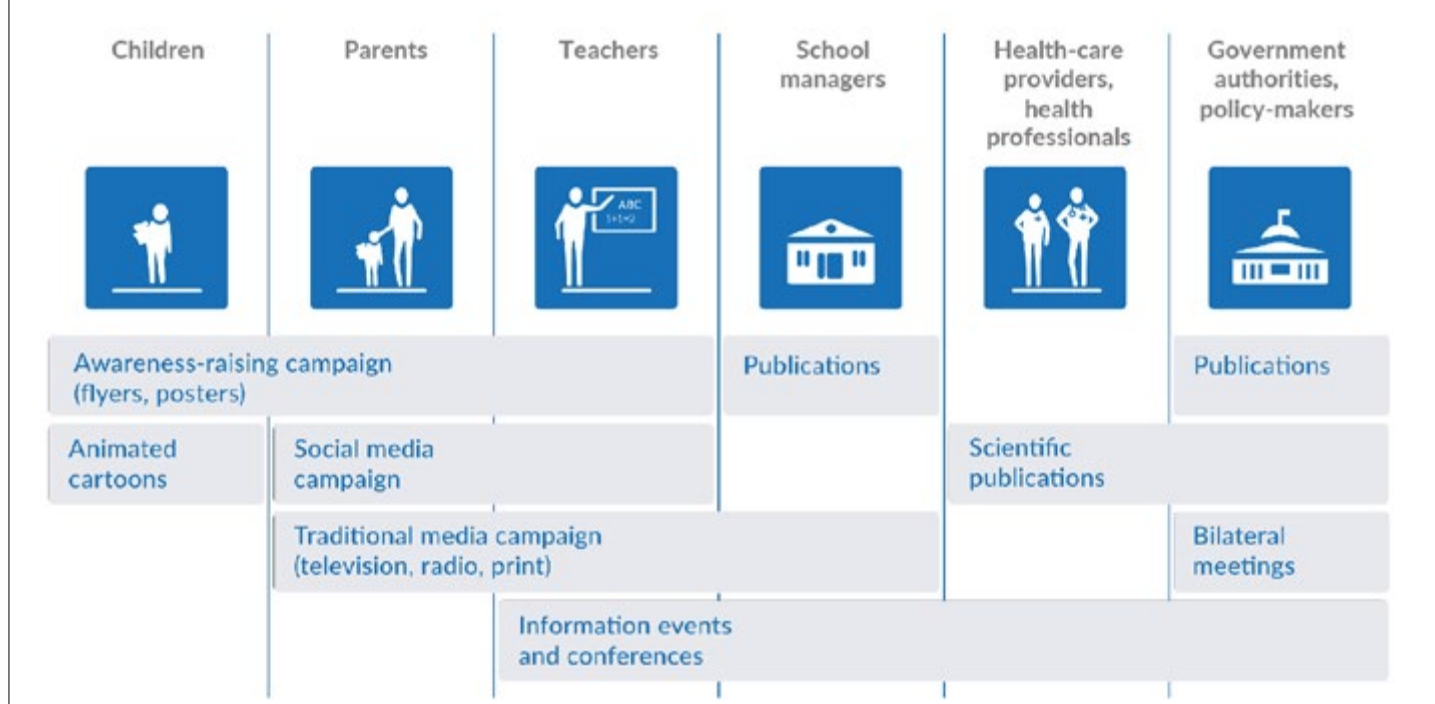
Interpersonal. People seeking advice or sharing information about health risks often turn to family, friends, health-care practitioners, co-workers, teachers, counsellors, and faith leaders. These one-on-one discussions are often the most trusted channels for health information.

Factors to consider when prioritizing channels include their reach (number of people that will hear, see, or read a message), and how the channel supports audiences' ability to recall the message and impact (whether the message results in action). Exposure to the message and repetition are key to audience recall, increasing the likelihood that audiences will act on the information provided.

References:

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

TARGET GROUPS AND CHANNELS



We reach specific target groups by using different communication tools with appropriate content and by using appropriate devices. The choice of which communication device to use must take into account the target group's relationship to a particular device. Thus the tools used for communication activities aimed at different target groups cannot be standardized.

References:

Lundgren RE, McMakin AH (2018). Risk communication: a handbook for communicating environmental, safety, and health risk. Sixth edition. New Jersey: Wiley-IEEE Press.

PLANNING A RISK COMMUNICATION STRATEGY

For whom	Why	What kind of information
School authorities	To identify the causes of indoor air quality problems and to plan for local measures to reduce risks and impact	Information on available intervention options (for example, availability of resources for installing mechanical ventilation)
Individuals who must adapt their behaviour (teachers, parents, students)	To educate and advise on how to change their behaviour	Information in an easy-to-understand form that allows people to grasp the link between certain activities/events and indoor air pollution, and that gives behavioural advice
Health-care providers and health professionals	To form scientific evidence bases and advocate for improving indoor air quality and reducing the health impact from long- and short-term exposure To ensure additional capacity and partnership	Detailed information on chemical pollutants and information on health impacts Information on independent evaluations and the latest scientific data
Government authorities, policy-makers	To promote measures at national and local levels aiming at the improvement of indoor air quality	Summary of available scientific information, national/local studies, health statistics data, decision-making options and their cost-effectiveness in plain language

An example of planning strategy to communicate risk of indoor air pollution is provided on the slide.

EVALUATION

Procedures need to be evaluated quantitatively and qualitatively.

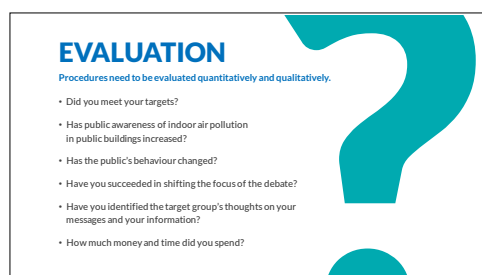
- Did you meet your targets?
- Has public awareness of indoor air pollution in public buildings increased?
- Has the public's behaviour changed?
- Have you succeeded in shifting the focus of the debate?
- Have you identified the target group's thoughts on your messages and your information?
- How much money and time did you spend?

Public health information campaigns require investments of scarce human and financial resources. It is important to measure the value of these investments in terms of money, time and effort. Risk communication efforts and programmes need to be evaluated regularly and systematically to determine their effectiveness and to make changes where needed. Communication aims and objectives must be clearly stated at the outset if an evaluation is to be effective. These aims could include the proportion of an at-risk population to be reached, the adoption of appropriate risk-reduction practices or the extent of resolution of the crisis. The best advice in evaluation exercises is to keep it simple and stick to common sense. Here are some of the questions you might consider for a campaign evaluation.

- Did the campaign achieve its objectives?
- Did it meet its targets?
- What worked and what did not?
- Have you succeeded in shifting the focus of debate?
- If you have been aiming at reframing your issue, are policy-makers now debating on your terms and asking relevant questions about health and the environment?
- Were you able to implement your follow-up strategy?
- What did your target groups think about the campaign and your information packs? Get a focus group of people to give feedback – not only on what they thought of the look of the materials and their messages, but whether they found the materials useful.
- How complicated and expensive was the campaign?
- Did you achieve partnerships with organizations related to academia, public opinion, the media or market research?
- Did you stay on budget? Itemize everything, including staff hours. Keep an eye on hidden costs, such as the extra telephone time, travel or reprinting costs needed to respond to inquiries. Look beyond external factors when you evaluate.

It is important to learn from both positive and negative risk communication experiences in order to adjust and improve ongoing activities. Only through systematic evaluations throughout the communication process can the communication process be strengthened.

continued



References:

Food and Agriculture Organization of the United Nations (FAO), WHO (1999). Strategies for effective risk communication [website]. Rome: FAO (<http://www.fao.org/3/x1271e/X1271E05.htm>, accessed 4 December 2019).

Lundgren RE, McMakin AH (2018). Risk communication: a handbook for communicating environmental, safety, and health risk. Sixth edition. New Jersey: Wiley-IEEE Press.

PanAmerican Health Organization (PAHO), WHO (2011). Risk communication presentation [website]. Washington, DC: PAHO (https://www.paho.org/disasters/index.php?option=com_docman&view=download&category_slug=caribbean-cholera&alias=1726-risk-communication-for-health-events&Itemid=1179&lang=en, accessed 4 December 2019).

Rohrmann B (1992). The evaluation of risk communication effectiveness. *Acta Psychologica*. 81(2):169–92. doi:10.1016/0001-6918(92)90004-W.

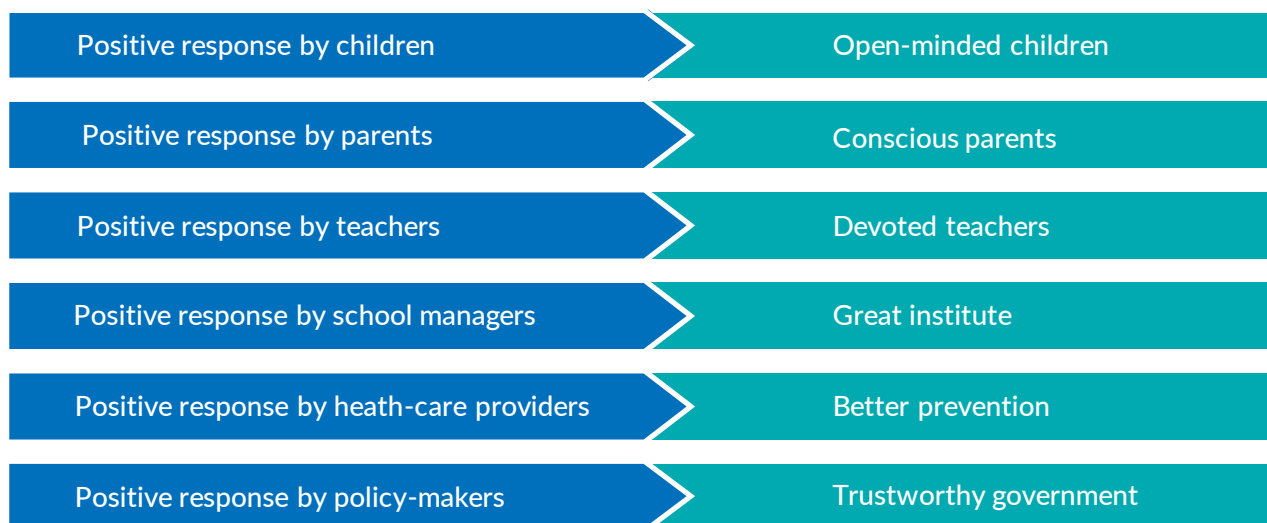
RECOMMENDATIONS – A SUMMARY

- Plan ahead.
- Identify key audiences, roles and resources.
- Concentrate on the most important target group.
- Focus on the requirements of the primary audience.
- Link the communication objectives to the primary audience.
- Define the communication objective and design the strategy accordingly.
- Address why, what, who and how.
- Consider expected outcomes.
- Evaluate the campaign and the lesson learned.

References:

WHO (2017). WHO Strategic Communications Framework for effective communications. Geneva: World Health Organization (<https://www.who.int/mediacentre/communication-framework.pdf>, accessed 9 November 2019).

POSITIVE RESPONSES BY TARGET GROUP: LONG-TERM RESULTS



10 GOLDEN RULES WHEN TALKING TO MEDIA

1. Use simple language, and avoid jargon.
2. Never lie.
3. Never say “no comment”.
4. Remember there is no such thing as “off the record”.
5. Be short and to the point, and always think of the audience.
6. Stay calm, confident and in charge.
7. Be human, and smile when appropriate.
8. It is okay to say “I don’t know but I’ll find out”.
9. Do not speculate.
10. Beware of reporters’ tactics.

The media are not your audience, but they need to understand your message and be motivated to convey it to your audience.

What reporters want is: numbers that are current and reliable; what is new; what is unexpected, surprising, or against “trend”; access to an expert or spokesperson who “gets to the point”; material in local language; good quotes, analysis and current information; photo and video images; respectful treatment; human interest stories.

One way to work with the media and to ensure a clear message is to prepare a soundbite. A sound-bite is a short, focused, clear quote that is easy to repeat and memorable when heard.

References:

WHO (2015). Effective communications: participant handbook for WHO staff. Geneva: World Health Organization (<https://apps.who.int/iris/handle/10665/249241>, accessed 1 October 2020).

CASE STUDY ON INDOOR AIR POLLUTION: AN EXAMPLE OF THE EFFECTIVENESS OF VENTILATION

- The study assessed the effectiveness of ventilation strategies in classrooms in the Flanders region of Belgium in 2006–2009.
- It studied more than 1500 children and 90 classrooms from 30 elementary schools.
- It determined that the carbon dioxide concentration in a classroom is a function of occupation density, activity and level of ventilation.

Results

- The study indicated that controlled ventilation was able to improve poor indoor air in Belgian classrooms.
- The lowest levels of carbon dioxide were found in ventilated classes.
- The biggest difference in indoor air quality between ventilated and non-ventilated rooms was found in wintertime due to cold outdoor temperatures.
- The ventilation rate could only be changed by arranging openings for incoming air, since the air outlets were fixed and did not allow for regulation.

Researchers conducted two studies of indoor air pollution in schools in the Flanders region of Belgium between 2006 and 2009. The Binnenlucht in Basisscholen (BiBa) study involved measuring a large number of indoor and outdoor air pollutants at 30 elementary schools in a total of 90 classrooms. The study included classroom inspections and assessment of exposure to wide range of pollutants (PM_{2.5}, PM₁₀, methyl tertiary-butyl ether, benzene, toluene, tetrachlorethene, ethylbenzene, xylene isomers, 1,2,4-triethylbenzene, total VOCs, formaldehyde, acetaldehyde, total other aldehydes, temperature, relative humidity and carbon dioxide), measurements of ventilation rates in classrooms, and measurements of respiratory function in more than 1500 children. The study demonstrated that properly arranged ventilation is effective for keeping indoor air clean.

References:

Csobod E, Annesi-Maesano I, Carrer P, Kephelopoulos S, Madureira J, Rudnai P et al (2014). SINPHONIE (Schools Indoor Pollution and Health Observatory Network in Europe): Final report. Luxembourg: Publications Office of the European Union (<https://op.europa.eu/en/publication-detail/-/publication/b1243a1b-317b-422f-b6cf-645b693b3cdf/language-en>, accessed 1 November 2019).

WHO (2011). Methods for monitoring indoor air quality in schools. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0011/147998/e95417.pdf, accessed 9 November 2019).

EXAMPLES OF KEY MESSAGES TO SPECIFIC TARGET GROUPS



MAIN MESSAGES



Be aware that there are many sources of harmful pollutants in indoor air – both outdoor and indoor sources contribute to indoor air pollution.



Joint actions by teaches, directors, parents, children and authorities are the most effective to ensure good indoor air quality.



Pollutants in indoor air can harm our health, and children are affected by pollutants more than adults as they are growing and developing.



Remember that your behaviour influences indoor air quality.

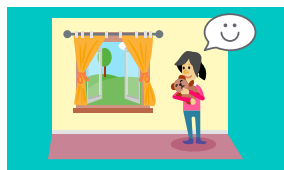


Measures to reduce indoor air pollution are well known – take your time to learn about them.



Environment tobacco smoking is dangerous for children's health.

SCHOOLCHILDREN



Be aware that indoor air quality is important for your health.

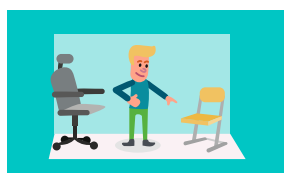
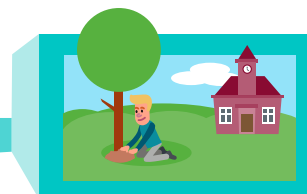


Promote healthy behaviour – be an example for your friends.

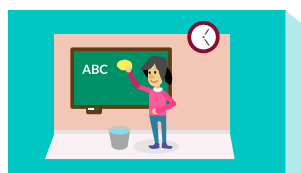
Actively support your teacher to create a cleaner school environment. A lot depends on you!



Make your school green indoors and outdoors.



Be picky – fancy and cool is not always safe and healthy. Ask your teacher and parents how to reduce pollution in your school environment.



Dust creates problems. Use a wet sponge to clean the blackboard. Clean or change your shoes to prevent dust in your school.

PARENTS



Be aware that hazardous chemical pollutants are always present in school and at home – learn about how to protect the health of you and your loved ones.



Ask for information on materials used for renovation, cleaning and ventilation.



Be active about indoor air quality in school – speak up for cleaner air.



Promote a healthy way of life in your family – bike, use public transportation and prioritize healthier products.



Pay attention to your child's complaints about smell, cough, eye irritation or headache – all of these can be caused by indoor air pollution.



Talk to your paediatrician if you are concerned about your child's health and ask for advice.

TEACHERS



Healthy children do better; you share responsibility for the health of your students.



Stay alert for children feeling unwell, and raise an alarm in case of an unusual smell.



Be aware of indoor air pollution and its health risks; learn more about how to improve the quality of the air in your classroom.



Advocate for eco-friendly products in your classroom, and do not overload the room with furniture and decorations.



Follow instructions on how to reduce indoor air pollution – ventilate or air classrooms during breaks, and keep the classrooms clean and green.



Communicate with parents and children for cleaner indoor air.



Show your students how to be friendly to the environment.

SCHOOL MANAGERS



Make your school healthy – this is just as important as educational indicators. Learn about the most effective measures to keep the air clean and fresh.



Plan renovation works carefully – emissions of hazardous chemicals from new building materials can be high.



Prioritize indoor air quality within the school budget.



Communicate with teachers, parents and students – do not hesitate to share concerns and seek help.



Investigate sources of indoor air pollution in your school; ask for advice from professionals if needed.



Let local health authorities know about any problems with indoor air, respiratory diseases or increased disease rates, and advocate for additional resources to address them.



Introduce mandatory maintenance/ventilation/airing protocols, and the use of eco-friendly and low-emission products.

HEALTH-CARE PROVIDERS



Be informed about the effects of indoor air pollution on children's health – prevent, diagnose and treat accordingly.



Promote actions at all levels – among students, parents, school staff and the local government – and be aware that regular airing and ventilation can be effective to keep indoor air cleaner.



Speak up about concerns if the air quality in and around schools is low – raise awareness among decision-makers.



Educate parents, families, students and school staff on how to do better.



Advocate for children's health and cleaner air in schools.



Engage with public health professionals and other supporters.

GOVERNMENT AUTHORITIES AND POLICY-MAKERS



- Be aware that indoor air quality in schools is a health determinant for children.
- Be involved in the planning of new schools, including their location – the air in schools near industrial sites and busy roads will be polluted.
- Ask professionals for advice on how to ensure good air quality in schools – make efforts to predict health risks for children.
- Equip all schools with a self-controlled ventilation system and a carbon dioxide alarm – these are effective for ensuring adequate indoor air quality.
- Ensure funding for good-quality and low-emission building products and furniture.
- Ensure regular, mandatory trainings on indoor air quality for school managers and teachers – they are the ones managing air quality onsite.

The WHO Regional Office for Europe

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

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