



HEALTH ASPECTS OF INDOOR AIR POLLUTION IN SCHOOLS

Training materials for school maintainers

Version 1
2019





A. Introduction

Surveys conducted in different climates around the world show that people generally spend about 80-90% of their time indoors. The quality of air in these indoor spaces therefore plays a very important role in the health status of the people regularly staying there.

First of all, we have to define: what do we mean by indoor spaces?

An indoor space or indoor area is any closed area surrounded by boundary elements (including the indoor space of vehicles).

Indoor Air Quality (IAQ) refers to the quality of the air inside buildings as represented by concentrations of pollutants and thermal (temperature and relative humidity) conditions that affect the health, comfort, and performance of the people staying inside. *(Note: Indoor air pollution is not considered to include technology-related air pollution in the workplace!)*

IAQ issues are especially important in schools because most children spend 6-8 hours or more (one third or one fourth of their time) at school where they have to perform intensive intellectual activity. The school is a special environment because it has to ensure optimum conditions for teaching and learning various kinds of subjects (mathematics, natural sciences, literature, physical education, foreign languages, etc.) for both the children and the teachers. Poor IAQ in school can interfere with the children's ability to concentrate and learn. We have to take into account that children - as developing organisms - are more sensitive to environmental impacts than adults. Low level of comfort leads to dissatisfaction. Acute effects of exposure to toxic chemicals like asthma attacks, headaches, nausea, drowsiness, and dizziness can be troubling in schools. Toxic chemicals can cause not only acute symptoms like irritations but long lasting adverse health damage, as well.

The Regional Priority Goal 3 "on preventing disease through improved outdoor and indoor air quality" of the Parma Declaration (2010) of WHO Europe, endorsed by 53



countries during the Fifth Ministerial Conference on Environment and Health, stated: “We aim to provide each child with a healthy indoor environment in childcare facilities, kindergartens, schools and public recreational settings, implementing WHO’s indoor air quality guidelines...”

There are several reasons why the quality of indoor air has attracted more and more attention in the past few decades. First of all, due to national and international efforts, the general level of outdoor air pollution has significantly decreased and so the indoor air sources until then disguised by the strong outdoor air pollution have come to light. Secondly, change of heating methods and construction materials (bricks replaced by air-tight concrete materials in the prefabricated technology) and the architectural efforts that have focused on reducing air exchange for better heat conservation and the increased insulation in existing buildings have led to increased pollutant concentrations in the indoor air. Thirdly, more and more plastics and other man-made materials and adhesives have been used in the construction and equipment of buildings, which emit a lot of highly volatile compounds and cause a great deal of new, unprecedented exposure. Fourthly, by reducing ceiling height and generally indoor air space, pollutants released into the indoor air can become very rapidly concentrated and reach concentrations that may already be harmful to health.

B. Types and sources of indoor air pollutants

The concentration of pollutants in a building depends on many factors like outdoor air quality, extent of air exchange, the binding capacity of indoor surfaces and the indoor pollution sources.

The fundamental difference between indoor and outdoor air is in the mixing volume. The mixing volume of the buildings is much smaller than that of the outdoor air. In this way, a pollutant that does not cause harmful effects outdoors, at most in the immediate vicinity of the emission, in the case of similar emission can reach dangerous concentrations indoors.



Indoor air is basically derived from *outdoor air*. Its quality thus largely determines the limits of indoor air quality. In case of contaminated ambient air, clean indoor air can be provided only by costly artificial methods. The most frequent outdoor air pollution sources influencing indoor air quality include traffic (proximity of busy roads for car and trucks, fuelled either by petrol or diesel), industry (power plants and other industrial plants), construction, waste deposit sites, and various kinds of agricultural activity (e.g. spraying pesticides).

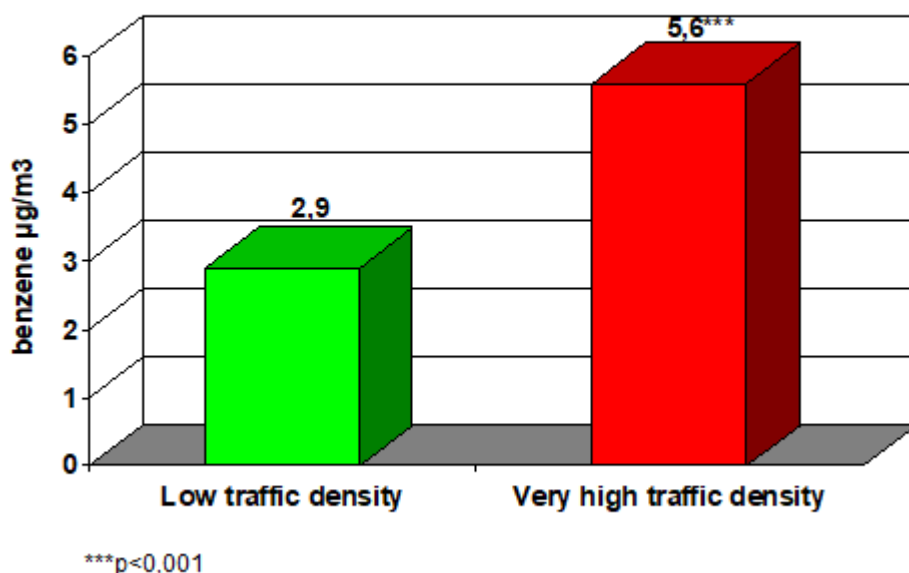
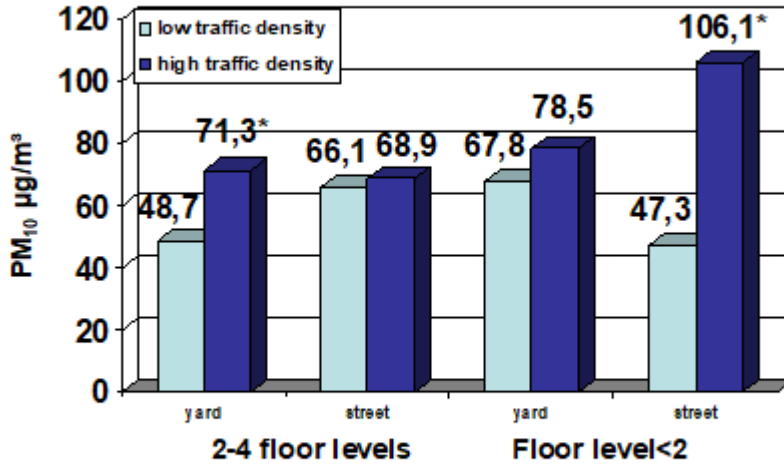


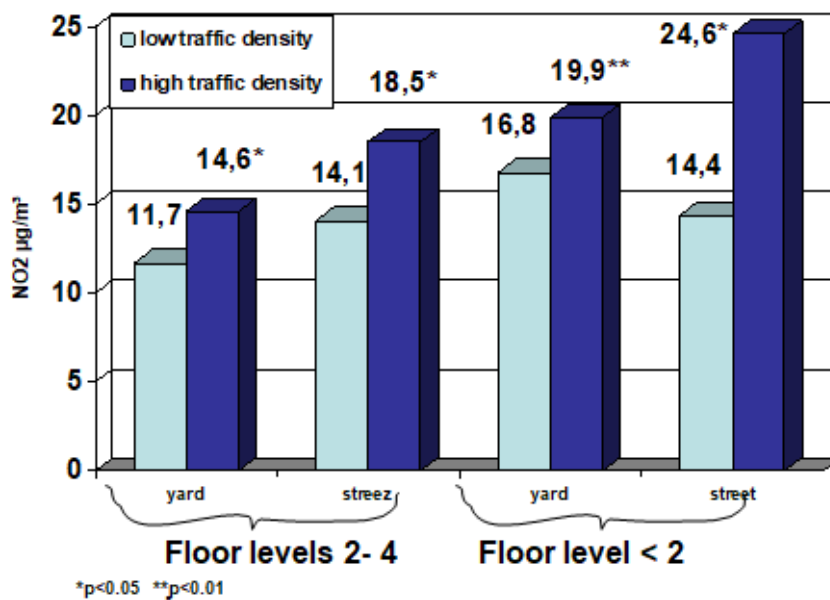
Figure 1. Mean benzene concentrations measured in classrooms in a neighbourhood of low or high traffic density (SEARCH Study, 2013)

Infiltration of outdoor air pollutants can be influenced by various factors. E.g. particulates tend to accumulate in the lower floor levels, especially in case of classrooms facing the street, while volatile organic compounds of outdoor origin can be measured in higher concentrations in classrooms in the upper than in the lower floor levels.



~p<0.1 *p<0.05 **p<0.01 ***p<0.001

Figure 2. Mean indoor PM₁₀ concentrations measured in classrooms by traffic density, street orientation and floor level (SEARCH Study, 2013)



*p<0.05 **p<0.01

Figure 3. Mean indoor NO₂ concentrations measured in classrooms by traffic density, street orientation and floor level. (SEARCH Study, 2013)



A large number of combustion products (carbon monoxide /CO/, nitrogen dioxide /NO₂/, sulphur dioxide /SO₂/, nitrogen oxides /NO_x/, particulates /PM/, polycyclic aromatic hydrocarbons /PAH compounds/) originate from various different sources like ambient air (traffic, power plants, industry), heating (stoves and fireplaces), environmental tobacco smoke (ETS), garages, parking lots nearby classroom windows, candles, sparklers and incenses, mosquito coils, etc.

However, special attention should be paid to substances released by indoor pollution sources. Accordingly, their concentration in indoor spaces will be higher than in the outdoor environment ($C_{\text{indoor}} / C_{\text{outdoor}} > 1$).

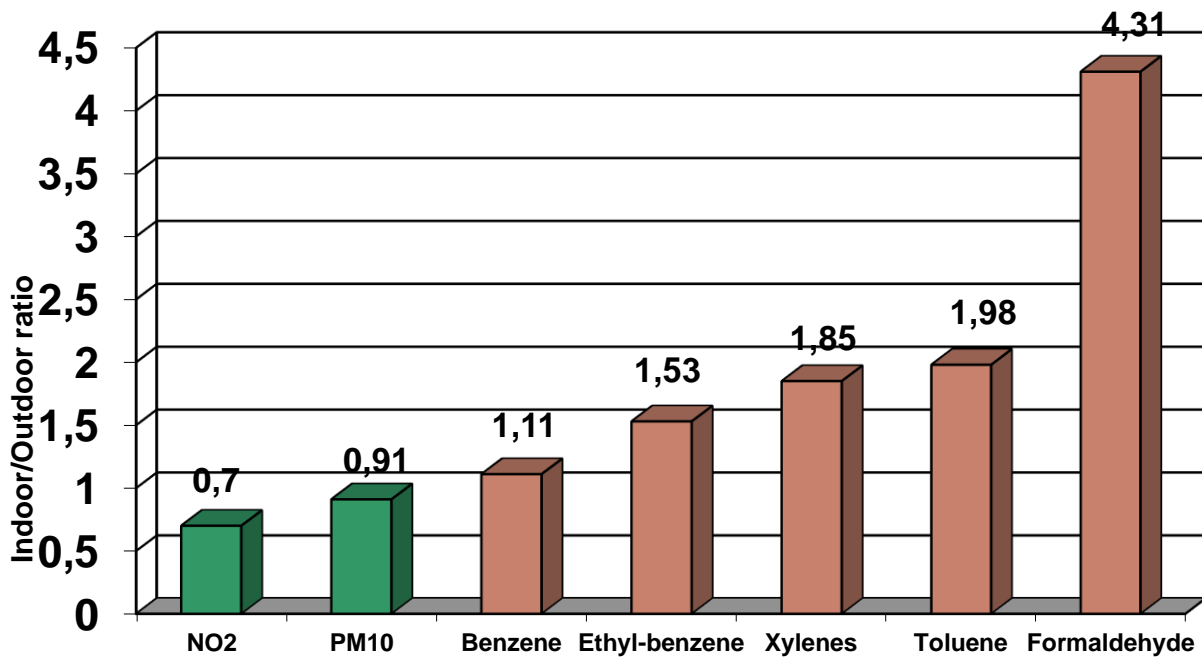


Figure 4. Ratio of pollutant concentrations measured outdoors and in the classrooms (SEARCH Study, 2013)

Figure 4 illustrates the ratios of the indoor and outdoor concentrations of the measured chemicals. It can be concluded that nitrogen dioxide (NO₂) and particulate matters with diameter less than 10 micrometres (PM₁₀) measured in the classrooms originate from the outdoor air while the other chemicals (benzene, ethyl-benzene, xylenes, toluene, and especially, formaldehyde) must have some indoor sources (as well).



Indoor sources of air pollutants in the classrooms also include dust, construction and insulating materials, wall and floor coverings and other surface materials, furnishing, paints, waxes, repellents, glues and resins, solvents, cleaning and disinfecting products, mould, photocopiers, inks, biocides, personal care products, humans, pets, rodents and insects.

Pollutants released by indoor sources include formaldehyde and other volatile organic compounds (VOCs), phthalates, polybrominated flame retardants, per- and polyfluorinated chemicals, vinyl chloride, trichloroethylene, tetrachloroethylene, ammonia, terpenes (limonene, alpha-pinene), phenol, naphthalene, asbestos.

Pollutants of outdoor origin entering and cumulating in the indoor air include radon, trichloroethylene, dust, particulates, polycyclic aromatic hydrocarbons, pollens, etc.

Besides the chemical air pollutants *biological air pollutants* (bacteria, viruses, mould, animal hair, skin flakes, faeces, urine, insects, dust mites, pollen, etc.) play also important role in the indoor air quality. Humidifiers, condensation water of poorly maintained air conditioners and indoor stagnant waters can serve as a substrate for bacterium proliferation. Moist surfaces and materials are most favourite places of mould growth. Allergens of animal origin (faeces of house-dust mites, birds' feather, cats' and dogs' fur, etc.) can be present in the indoor air months after the removal of the source. Droplets from coughing and sneezing of infected people contain high number of bacteria and viruses which can live on in the indoor environment for several days.

Most frequent sources of mould development are rising dampness (capillary-like absorption of groundwater into the structural elements of the building due to bad insulation), penetrating dampness due to leaking, rain, melted snow (through the roof, walls or joints) and condensation due to excessive vapour production or inadequate ventilation, inadequate heating, large cold surfaces or cold bridges.



C. Health impact of indoor air pollution

Pollutants occurring in the indoor air may cause adverse effects in various organs and organ systems of the human body. The most obvious signs of health impairment appear at the entrance of the exposure route, i.e. in the respiratory system, but the cardiovascular, the central nervous and the immunological system as well as the endocrine system may also be affected by short term (acute) or long-term (chronic) exposures.

Acute effects in the respiratory system elicited by indoor air pollutants include mucous membrane irritation in the eyes and the upper respiratory tracts, coughing (symptom of bronchitis), asthmatic symptoms like wheezing, attacks of dyspnoea (heavy breathing), increased responsiveness of the airways to allergens and increased acute respiratory morbidity (due to upper- and lower respiratory tract infections, pneumonia, otitis media, etc.) reflecting impairments of the immune system, too. The increased risk of infection is also indicated by the increased absenteeism from school due to sore throat, cough, and cold, and by increased levels of biomarkers of oxidative stress and inflammation. Chronic exposure to certain pollutants may cause reduction of lung function and development of chronic obstructive pulmonary disease (COPD) and even lung cancer.

Some indoor pollutants may cause elevations in the arterial blood pressure and the heart rate.

Impacts of exposure to certain indoor air pollutants on the central nervous system may manifest themselves in headache, fatigue, dizziness, nausea and impaired task performance. Chronic exposure may cause impairments in different neuropsychological development outcomes (cognitive and psychomotor development delays, decreased global IQ, learning disabilities, difficulties in reading comprehension, memory functions, reading and maths scores, reduced reaction speed, attention deficit, coordination problems). Prenatal and early childhood exposure can result in neurodevelopmental diseases (attention deficit/hyperactivity, autism spectrum disorders, etc.).



Some chemicals exert endocrine disrupting effects manifesting themselves in impairments of the reproductive system, disorders in the brain development, contribution to later onset of diabetes, obesity, hyper- or hypothyroidism.

Exposure to certain air pollutants are known to be associated with childhood leukaemia and some central nervous system tumours in children. Childhood exposures may also contribute to the development of other cancers in the later life, as well.

D. Sources and health impacts of individual indoor air pollutants

Nitrogen dioxide (NO₂)

Most of the nitrogen dioxide in the classroom air comes from vehicle exhaust gases of the outdoor air (indoor/outdoor concentration ratio is about 0.8), and from heating (in case of schools with gas heating appliances with inadequate ventilation). In addition, smoking may significantly contribute to the indoor NO₂ concentration where it is not yet prohibited.

Epidemiological studies have shown an increase in the incidence of chronic lower respiratory tract diseases at chronic concentrations of 94 to 282 µg/m³. Further health effects observed: increased bronchial reactivity, reduced respiratory function, reduced immunological protection, middle ear, nose-, ear-, and pharynx inflammation, eczema, increased blood coagulation in adults and increased allergenic effect of allergens (e.g. food allergy). Children and asthma patients are particularly sensitive to the effects of NO₂.

Health-based limit values for indoor NO₂ concentrations were recommended by the WHO: 200 µg/m³ (1 hour average) and 40 µg/m³ (annual average).



Carbon monoxide (CO)

Indoor carbon monoxide may come from a variety of sources: the inflow of ambient air pollution produced mainly by cars, buses and trucks, or any kind of other outdoor CO sources (power plants, incinerators and other industrial pollution) as well as the use of poorly adjusted gas appliances, and smoking.

The health-damaging effect of carbon monoxide is primarily due to its strong tendency to bind to haemoglobin, as it impedes the binding and transport of oxygen by haemoglobin and thus causes tissue hypoxia throughout the body. As a result, the most sensitive organs to oxygen deficiency (myocardium, central nervous system), may be affected, producing more and more serious acute symptoms depending on the exposure level (headache, vertigo, tiredness, heavy breathing, nausea, vomiting, irritability, drowsiness, confusion, disorientation, loss of consciousness, coma and death). Chronic CO exposure may cause ischemic heart disease, acute myocardial infarction (AMI), increased cardiovascular and total mortality, asthma, sinusitis and pneumonia. Patients with impaired cardiac muscle, anaemia, chronic respiratory disease and cerebrovascular disease, and the elderly are particularly susceptible to this damage. Lack of oxygen can also adversely affect foetal development, which can result in retardation in foetal development, reduced birth weight and congenital malformations.

The WHO Guideline recommends a limit value of 100 mg/m³ for 15 minutes, 35 mg/m³ for 1 hour, 10 mg/m³ for 8 hours and 7 mg/m³ for 24 hours.

Ozone (O₃)

At ground level ozone is not emitted directly, but it is created by chemical reactions between NO_x and VOCs in the presence of sunlight and heat. Increased indoor ozone level of anthropogenic origin can be the result of intensive use of copy machines and other ozone producing instruments. Ozone generators have become popular in some industrialized countries. They are used to produce high concentrations to disinfect, deodorize, or for chemical decontamination of spaces not intended for human staying. Scientific evidence shows that, at concentrations that do not exceed public



health standards, ozone has little potential to remove indoor air contaminants: there is no approval for its use in occupied spaces.

When inhaled, ozone can damage the lungs. Relatively small amounts can cause chest pain, coughing, shortness of breath and throat irritation. Ozone may also exacerbate chronic respiratory diseases such as asthma and compromise the ability of the body to fight respiratory infections. People vary widely in their susceptibility to ozone.

(www.epa.gov/iaq/pubs/ozonegen.html)

WHO Air Quality Guideline for Europe (2nd ed.) set a guideline value of ozone for 8 hours at 120 µg/m³.

Formaldehyde

Formaldehyde can be released from a variety of plastics and furnishings, insulation materials, laminated and extruded plastic products based on urea, melamine or phenol-formaldehyde resins, adhesives, disinfectants and preservatives. The amount of formaldehyde released depends on the technology used and the conditions of use. Raising air temperature or relative humidity and intense UV radiation can increase emissions by several times. Traffic (exhaust emission) is an important outdoor source of formaldehyde concentration.

Formaldehyde has been classified by the WHO International Agency for Research on Cancer (IARC) as a human carcinogen (Group 1). Formaldehyde causes irritation of the mucous membranes of the respiratory tract (irritation), inhibits ciliary movement of the mucous membranes in the respiratory tract and thus impairs the local defence mechanism. It is a strong allergen (sensitizer). The irritant effect is usually observed at concentrations above 100 µg/m³, while the sensitizing effect can be detected at lower concentrations. People exposed to chronic formaldehyde exposure are more likely to have chronic rhinitis and coughs, chronic airway obstruction and difficulty in breathing. People with allergic or inflammatory respiratory disease may be particularly sensitive to formaldehyde exposure.

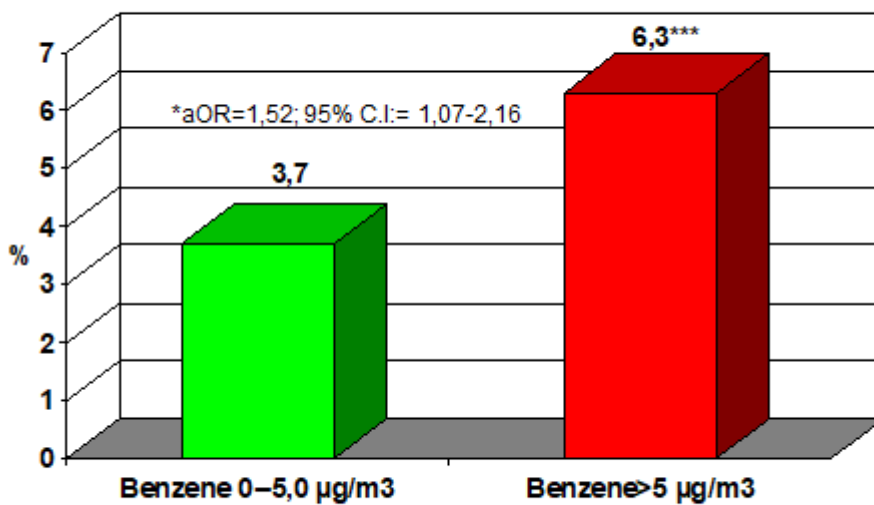
The odour threshold for 10% of the population is at 30 µg/m³, for 50% is at 180 µg/m³ and for 90% is at 600 µg/m³. The WHO recommended a guideline value of 100 µg/m³ for 30 minutes.



Benzene

Sources of benzene in ambient air include cigarette smoke, combustion and evaporation of benzene-containing petrol (up to 5% benzene), petrochemical industries, and combustion processes. Benzene concentrations in air are higher near such sources of benzene emission as filling stations.

Benzene is present in both outdoor and indoor air. However, indoor concentrations are generally higher than those in outdoor air owing to the infiltration of benzene present in outdoor air and to the existence of many other indoor sources. Main sources of indoor benzene concentration in schools may include varnishes, paints, adhesives, solvents and chemicals used for cleaning, or some building materials that off-gas benzene.



(*adjusted for: age, gender, parental smoking, home living density, country)

Figure 5. Prevalence of children woken up by night by wheeze in classrooms with benzene concentrations of 0-5 µg/m³ or above (SEARCH Study, 2013)

Inhalation is the dominant pathway of benzene exposure in humans. Acute toxicity of inhaled benzene manifests itself in euphoria, nausea, vertigo, cramps, loss of consciousness, and respiratory arrest. Chronic exposure to benzene may result in asthmatic symptoms (like woken up by wheeze - see Figure 5), immunological



disturbances, chromosome aberrations and haematological disorders (bone marrow anaplasia, leukaemia). Benzene is a genotoxic carcinogen in humans (IARC Group 1) and no safe level of exposure can be recommended. Based on its estimates WHO recommended a yearly average guideline value of $5 \mu\text{g}/\text{m}^3$.

Toluene

Toluene occurs naturally at low levels in crude oil and is a by-product in petrol production or the production of coke from coal. Toluene is a common solvent, e.g. for paints, paint thinners, silicone sealants, many chemical reactants, rubber, printing ink, adhesives (glues), lacquers, leather tanners, and disinfectants.

Toluene has moderately or strongly toxic properties: it damages the brain and the nervous system, though it is much less toxic than benzene, and as a consequence, largely replaced it as an aromatic solvent in chemical preparation.

Direct inhalation of toluene in low to moderate levels can cause tiredness, confusion, weakness, drunken-type actions, memory loss, nausea, loss of appetite, hearing loss and colour vision loss. Some of these symptoms usually disappear when exposure is stopped. Inhaling high levels of toluene in a short time may cause light-headedness, nausea, or sleepiness, unconsciousness, and even death. Chronic toluene exposure may cause disruption of foetal development resulting in spontaneous abortion, developmental disorder or intrauterine growth restriction (IUGR). However it is neither genotoxic, nor carcinogen.

As a guideline value, WHO recommends a weekly average concentration of $260 \mu\text{g}/\text{m}^3$, which has a good protective effect in terms of reproduction, too.

Xylenes

The xylene isomers or their mixture, called *as xylenes, are used as a solvent*. They are used in printing, rubber and leather industries and they are a cleaning agent, too. Xylenes are a common component of ink, rubber and adhesives. Due to their less toxic properties, xylenes can be substituted for toluene.

Direct inhalation of xylenes may affect the central nervous system causing headache, dizziness, nausea and vomiting. Long-term exposure may lead to headaches,



irritability, depression, insomnia, agitation, extreme tiredness, tremors, liver and kidney damage, hearing loss, impaired concentration and short-term memory loss. Xylenes are also a skin irritant.

Naphthalene

Most naphthalene is derived from coal tar. It is used mainly as a precursor to other chemicals like azo-dyes and certain insecticides, deodorants and disinfectants. In a sealed container naphthalene vapours may build up to levels toxic to both the adult and larval forms of moths that attack textiles.

The International Agency for Research on Cancer (IARC) classifies naphthalene as possibly carcinogenic to humans and animals (Group 2B). The IARC also points out that acute exposure causes cataracts in humans, rats, rabbits, and mice; and that haemolytic anaemia can occur in children and infants after oral or inhalation exposure or after maternal exposure during pregnancy.

The WHO Indoor Air Quality Guideline recommended an annual average guideline concentration of 10 µg/m³.

Mothball and other products containing naphthalene have been banned within the EU since 2008.

Trichloroethylene

Trichloroethylene (TCE) is a chlorinated solvent, its artificial production is justified by its wide-ranging industrial use (degreasing of metals, cleaning of textiles, extraction processes, etc.). 60-90% of TCE produced annually is eventually released into the environment, partly to air and partly to water. Concentrations of TCE in cities are generally found to be three times higher than in rural areas.

Inhalation of airborne trichloroethylene is the major route of exposure for the general population. This may result from the use of TCE-containing materials (wood stains, varnishes, coatings, lubricants and adhesives, paint strippers and cleaning agents) in poorly ventilated areas or from TCE contamination of tap water.

The main health effects of concern with trichloroethylene are cancer, and effects on the liver and the central nervous system. IARC classified trichloroethylene as a Group



2A carcinogen (probably carcinogenic to humans). In epidemiological studies positive associations were observed between exposure to trichloroethylene and risks for cancer of the liver and biliary tract and non-Hodgkin lymphomas

In subjects exposed to trichloroethylene for prolonged periods, central nervous system symptoms (headache, fatigue, irritability, alcohol intolerance) are most common, but signs of renal and hepatic impairment have also been observed.

The ranges of ambient air concentrations of trichloroethylene corresponding to an excess lifetime risk of 1:10,000, 1:100,000 and 1:1,000,000 are 230, 23 and 2.3 $\mu\text{g}/\text{m}^3$, respectively.

Tetrachloroethylene

Indoor air levels of tetrachloroethylene may be increased in close proximity to dry-cleaning operations where tetrachloroethylene is used as a cleaning solvent or in homes where dry-cleaned clothing is often worn. Inhalation of tetrachloroethylene is the major route of exposure in the general population.

The main health effects of concern are cancer and effects on the central nervous system, liver and kidneys. Tetrachloroethylene is classified by IARC as a Group 2A carcinogen (probably carcinogenic to humans). Epidemiological studies in humans showed positive associations between exposure to tetrachloroethylene and risks for oesophageal and cervical cancer and non-Hodgkin lymphoma. On the basis of the kidney effects of long-term tetrachloroethylene exposure in dry-cleaning workers, a guideline value of 0.25 mg/m^3 was calculated.

Vinyl chloride

Vinyl chloride is a volatile chemical intermediate in the production of PVC. In the environment it is created in water under anaerobic circumstances from trichloroethylene and tetrachloroethylene. It gets from the water into the air where its half-life is calculated to be 20 hours. The primary exposure route of VC is inhalation, or in a lesser extent, per os. After entering the body, vinyl chloride is converted into highly reactive and mutagenic metabolites.



The acute toxicity of VC is low but it is toxic to the liver, even at low or short term exposure. VC has been shown to be mutagenic in various in vivo and in vitro systems. There is sufficient evidence of human carcinogenicity of VC (IARC Group 1). Haemangiosarcoma of the liver has clearly been shown to be causally related to human vinyl chloride exposure. Several studies have confirmed that VC exposure can cause other cancers as well: liver cancer, brain cancer, lung cancer, and malignant lymphatic and haematopoietic malignancies.

Concerning its guideline value, vinyl chloride is a human carcinogen and the critical concern with regard to environmental exposures to VC is the risk of malignancy. Therefore no safe level can be indicated. Estimates based on human studies indicate a lifetime risk from exposure to $1 \mu\text{g}/\text{m}^3$ to be 1×10^{-6} . (WHO, 2000)

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are complex mixtures of hundreds of chemicals formed during incomplete combustion or pyrolysis of organic materials and in connection with the worldwide use of oil, gas, coal and wood in energy production. Additional contributions to air levels arise from tobacco smoking, and the use of unvented heating sources can increase PAH concentrations in indoor air. Because of such widespread sources, PAHs are present almost everywhere.

Data from animal studies indicate that several PAHs may induce a number of adverse effects, such as immunotoxicity, genotoxicity, carcinogenicity and reproductive toxicity (affecting both male and female offspring), and may possibly also influence the development of atherosclerosis. The critical endpoint for health risk evaluation is the well documented carcinogenicity (IARC Group 1) of several PAHs (IARC, 1983).

The corresponding concentrations of BaP producing excess lifetime cancer risks of 1/10,000, 1/100,000 and 1/1,000,000 are 1.2, 0.12 and 0.012 ng/m^3 , respectively (WHO, 2000).

Phthalates

Phthalates are a group of industrial chemicals that add flexibility and resilience to many consumer products like tablecloths, furniture, vinyl flooring, shower curtains,



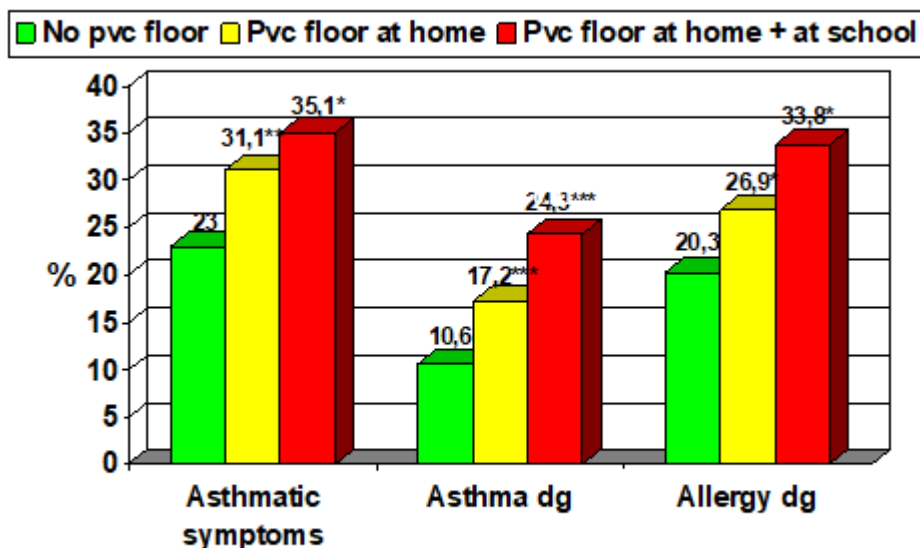
garden hoses, inflatable swimming pools, plastic clothing such as raincoats, children's toys, automobile upholstery, etc. Some phthalate compounds are used in nonplastic consumer items as fixatives, detergents, lubricating oils, and solvents and can be found in carpets, paints, glue, insect repellents, time release capsules, and personal care products such as soap, shampoo, hair spray, nail polish, deodorants, and fragrances. In schools, e.g. pvc flooring may contain phthalates as plasticizers. Phthalates are easily released from the plastic products in which they are used as there is no covalent bond between phthalates and the plastics in which they are mixed.

People are exposed to phthalates through inhalation of contaminated air, orally by consumption of contaminated water or food (as the phthalates in plastic packaging may leach into the food they hold), or through direct contact with consumer products containing phthalates.

Several studies have reported associations between phthalate exposure and asthma and allergic diseases, and certain adverse neurodevelopmental outcomes. The importance of reproductive and developmental effects of some phthalate exposure should be underlined in relation to the school environment.

Although people are continually exposed to phthalates because they are ubiquitous, you can minimize re-exposure to phthalates by avoiding products containing PVC plastic, e.g. when remodelling schools, kindergartens and other childcare facilities avoid the use of PVC/vinyl floors.

Figure 6 illustrates the above mentioned associations: prevalence of asthmatic symptoms and doctor-diagnosed asthma or allergy was found significantly higher among children living in homes with pvc floor and even much higher among those whose floor in both the flat and the classroom was fitted with pvc than those children without exposure to pvc floor.



OR=1,78* (95% MT:1,07-2,96) OR= 3,21*** (1,79-5,73) OR= 1,77* (1,07-2,93)

Figure 6. Association between pvc floor and prevalence (%) of respiratory symptoms and diseases, respectively, among Hungarian schoolchildren (SEARCH Study, 2013)

Pesticides

Pesticides are chemicals that are used to kill or control pests (bacteria, fungi, termites, insects and rodents). Products used indoors most often are insecticides and disinfectants in the form of sprays, liquids, sticks, powders, crystals, and balls. Pesticides are classified as semi-volatile organic compounds.

Pesticides are inherently toxic. Problems related to the indoor use of pesticides may be due to the fact that generally greater concentrations of pesticides can be found and stay on longer near the floor and can be resuspended (e.g. in the classroom air). Sometimes pesticide application is too frequent, too extensive and in some cases unnecessary.

Exposure to pesticides may result in irritation to eye, nose and throat, damage to the central nervous system and kidney and may increase the risk of cancer. Acute exposure generally happens incidentally and may induce symptoms like headache, dizziness, muscular weakness and nausea. Chronic exposure to some pesticides can



result in asthma and allergies, damage to the liver, the kidneys, the endocrine and the nervous systems, degenerative diseases (Parkinson's disease) and cancer (leukaemia, non-Hodgkin lymphoma). However, there is insufficient understanding at present about what pesticide concentrations produce these effects.

Asbestos

Asbestos has been used in buildings for decades because of its excellent thermal and electrical insulation and refractory properties. Other possible sources of environmental exposure include corrugated and flat roofing sheets, car breaks, pipes transporting air, gas, water, and wastewater, etc. Asbestos fibres can enter the body by inhalation or ingestion, and a few decades later may cause cancer of the pleura and peritoneum (mesothelioma) and lung cancer. Once installed, asbestos can be safe for long periods of time if left undisturbed. However, aging asbestos structures can release more and more fibres into the air and thus into the body. However, the greatest danger can be the removal of asbestos if it is carried out by a person with inadequate skills and without proper protective equipment.

Due to its carcinogenic property (IARC Group 1) use of asbestos has been banned in most countries, with some very few exceptions. However, due to its long-term usage asbestos fibres are expected to occur in the outdoor and indoor air for many decades. No safe level can be proposed for asbestos because a threshold is not known to exist. Exposure should therefore be kept as low as possible. Based on the results of epidemiological studies, WHO estimated a lifetime exposure to 1000 fibres/m³ to cause 1 excess lung cancer death per 100,000 - 1,000,000 population.

Radon

Exposure to radon and radon progeny is the dominant source of exposure to ionizing radiation in most countries. The radon levels vary considerably between indoor spaces, and depend primarily on the inflow of soil gas, water pipes and the type of construction materials (additives, e.g. fly ash from thermal power plant, blast furnace slag, etc. added to the natural radioactive material content of the building



material). Basements and cellars play important role in reducing exposure. Good ventilation can also greatly improve the situation.

Inhalation is the main route of radon exposure. Radon is a well-documented human carcinogen (IARC Group 1) causing lung cancer. Smoking increases the risk of lung cancer in a multiplicative way. Leukaemia has also been proven to be associated with radon exposure.

As radon is a known human carcinogen with genotoxic action, no safe level of exposure can be determined and no guideline value for radon concentration can be recommended. Nevertheless, the risk can be reduced effectively based on procedures that include optimization and evaluation of available control techniques. In general, simple remedial measures should be considered for buildings with radon progeny concentrations of more than 100 Bq/m³ equilibrium equivalent radon as an annual average, with a view to reducing such concentrations wherever possible (WHO, 2000).

Microbial pollutants

During sneezing, coughing and speaking, mucus - especially the mass of saliva droplets - leaves the body, carrying microorganisms from the nose, pharynx and lungs (bronchi). For example, when sneezing, hundreds of thousands of droplets smaller than 100 microns and thousands of larger droplets get into the air. Larger droplets settle on the floor or the surface of objects within a few seconds, within 1-2 meters. The smaller droplets evaporate immediately, leaving behind solid particles of 1-10 microns in size which remain suspended in the air and are thus easily inhaled. The settled dust may re-mix during increased air movement or human activity. The sedimentation rate of the particulates depends on the size of the particles. Some pathogen bacteria can survive for days, weeks, and sometimes months at room temperature, especially when not exposed to sunlight. After using the toilet, the aerosol formed during flushing may remain in the air for 4 hours and disperse the intestinal bacteria and viruses contained therein, which may settle in large quantities on the surface of the equipment or be inhaled.



Some of the aspects that will help to reduce the amount of microorganisms in the indoor air, or keep it at an acceptable level without increasing the incidence of the disease are listed below:

Providing adequate natural ventilation, the concentration of airborne microorganisms will "cool down", meaning that the number of microorganisms per specific volume of air will decrease.

Classrooms should be exposed to direct sunlight containing UV rays, which can kill most bacteria (bactericide effect). It is especially important to take advantage of the natural sunlight's bactericide effect in the toilet as well. (It is worth mentioning that not only direct sunlight but also spread daylight has a bactericide effect.) Classrooms should be constructed in such a way that cleaning can be thorough and efficient. In particular, the surfaces of floors, walls and ceilings should be so smooth that they are easy to clean. All the zigzags in the school building should be accessible for cleaning, and dust traps should be avoided wherever possible. Providing a relative humidity of about 50% significantly reduces the content of airborne microorganisms. Proper use of the indoor spaces (proper ventilation, regular cleaning, disinfection of the toilet and bathroom, avoiding overcrowding, etc.) is also required to ensure a low germ count. When vacuuming, open the windows so that fine dust particles escaping from the vacuum cleaner bag can escape freely and no longer circulate in the classroom air.

Fungi, especially mould

Moulds are a large and diverse number of fungal species. These simple nutrient demanding fungi grow fast in the presence of high relative humidity (>70%), producing a large number of tiny spores that are easily transported through the air. The size of the spores ranges from 1 to 100 μm and can get down to different depths of the respiratory system. Allergic symptoms caused by spores are related to the location of the spores: spores larger than 10 μm in the nasal passages may cause allergic rhinitis, 4-10 μm spores in the bronchi and bronchioles may cause asthma, and the spores smaller than 1 μm can cause alveolitis (inflammation of the wall of the alveoli). Other allergic symptoms may include rash, eczema, gastrointestinal allergy (diarrhoea), allergic conjunctivitis.



Under normal conditions, the body can cope with 100 to 500 spores per cubic meter. However, a higher spore load will eventually lead to a state of hypersensitivity, whereby a lower number of spores that has not previously elicited a response will trigger an allergic reaction.

The underlying cause of mould is excessive humidity in the indoor air and condensation. The following circumstances make this possible: increased humidity production, lack of ventilation, insufficient ventilation because of deficiencies due to highly air-tight doors and windows or blocked vents, plastic coverings that cannot remove moisture, and wall structures that reduce vapour diffusion. Reduced, often intermittent heating causes the boundary surfaces to cool down and condensation appear. Reduced air temperature may lower the humidity capacity of the air, so excess water is precipitated. (It is known that the humidity capacity of the air depends on the temperature: the air can contain more water at higher temperatures and less water at lower temperatures. The difference will precipitate at lower temperatures.) Due to construction defects (e.g. thermal bridges) or poor insulation, the boundary walls are cooled in various areas and condensation may occur.

Since the conditions leading to mould formation in the various indoor spaces vary greatly, the specific cause should always be identified in order to be able to eliminate the underlying conditions.

Sick Building Syndrome (SBS) and Building Related Illnesses should also be mentioned among the health impacts of IAQ. The SBS is characterized by non-specific symptoms (headache, fatigue, eye, nose or throat irritation, itchy skin, wheezing, change of taste sensation, hoarseness of voice, etc.) that are apparently linked to the time of learning/teaching/working indoors and clear when away from the building. Their appearance is difficult to trace to a specific source. Some specific features were identified, e.g. SBS tends to occur in air-conditioned buildings where the windows can't be opened, or in buildings with very bright and/or flickering lights, or where ventilation, heating, lighting can be insufficiently controlled, where there are carpets or upholsteries with large surfaces or many open shelves or storage compartments. New furniture, carpet or painted surface, neglected maintenance, insufficient



cleaning, high temperatures or large temperature fluctuations, very low or very high humidity, chemical pollutants like cigarette smoke, ozone, or VOCs from building materials or equipment, particulate matters and fibres in the air, as well as computer monitors have been identified in some or other cases as possible causes of SBS but not every building can be considered sick where one or more of the mentioned factors occur.

A lot of complaints are associated with inadequate ventilation either through ineffective removal of indoor air pollutants or by insufficient supply of fresh air. Insufficient natural ventilation causes increased moisture/mould, enhanced concentration of bacteria/viruses/fungi and chemical pollutants (e.g. several volatile organic compounds like benzene, xylenes, toluene) and unpleasant odours. In classrooms the total volume of air should be exchanged 5 times/hour.

Symptoms may not disappear upon leaving the building. Recognized building related diagnoses include infections (cold, flu, Legionnaires' Disease, Aspergillosis in immune-

Prevention of Sick Building Syndrome (SBS) needs to pay attention to various details during planning, design, implementation and operation of schools alike.

In the planning phase it is important to think over whether there are no hidden problems at the site (high level of ground water, radon emanation or other pollution sources, etc.). All possible risk factors should be considered like appropriate ground-plan, easy cleanliness, appropriate heat factors, etc., the quality of ambient air (if bad, was it considered during ventilation and insulation design?)

During operation ventilation should be correctly set. Poor adjustment (inadequate ventilation or drought) is a common cause of SBS. Regular and proper cleaning should be performed (surface contamination is a common cause of SBS), hidden damp and wet areas should be eliminated, right operation of ventilation equipment and filters should be ensured, considering also the aspects of cleaning. Comfort factors should also be considered: noise from equipment and ventilation system should be reduced as much as possible, appropriate temperature and relative humidity should be provided, etc.



Contribution of indoor air pollution to the disease burden in Europe

Public health significance of indoor air pollution was evaluated in the Final Activity Report of the ENVIE Project (Co-ordination Action on Indoor Air Quality and Health Effects) by presenting the contribution of non-ideal IAQ to symptom and disease burden in the European countries expressed in DALYs (Disability-Adjusted Life Years). From these figures it can be concluded that the quality of outdoor air is responsible for about 54% of the life years lost due to poor indoor air quality and the indoor-related components (water systems, mould, heating and ventilation systems, etc.) are responsible for the remaining 46%. Among the indoor air pollutants combustion products have the biggest share of life years lost (39%) but bioaerosols are not much behind them (36%), and VOCs are in the third place (16%). Asthma (30%) and cardiovascular diseases (31%), as well as Sick Building Syndrome (23%) are the leading health problems as far as life years lost due to poor indoor air quality.

In the last two decades very successful international epidemiological studies have been carried out in Europe which resulted in clear messages about the need to improve planning, design, construction, maintenance and operation of schools in order to ensure healthy environment for both the children and the teachers.

E. Management of indoor air quality in schools

Teachers, staff, and other members of the personnel together with the school maintainer can contribute to the improvement of indoor air quality in the classrooms and the school. There are some suggestions that we'd like to offer to promote those efforts.

One of these suggestions is about the *classroom environment*. Furniture and equipment should be arranged to best assist teaching and learning and to allow for easy moving. All students should be seated in areas that allow them to see the blackboard. Students and teachers should have adequate personal work space. A floor space of at least 2 m²/child should be guaranteed in the classroom. Comfort environment (appropriate heat, ventilation and light) should be provided for optimal



teaching efficiency. External noise levels should not interfere with learning. Direct glaring sunshine should be prevented by shading.

Overcrowding in the classroom should be avoided because it results in higher levels of chemical air pollutants (CO₂, PM, etc.), increased risk of pathogen transmission (infection), higher noise level, decreased attention, more frequent cases of fatigue and headache, and increased risk of accidents.

Maintenance of adequate indoor air quality should pay attention to three aspects of IAQ: source control, ventilation and air cleaning.

Source control. Concentrations of indoor air pollutants should be kept as low as possible but in no ways should the concentration exceed the guideline values set by national or international bodies.

WHO recommended guideline values for some frequently occurring indoor air pollutants which are expected to be internalized in the national law. In some countries there are health limit values or at least guideline values for indoor air pollutants while in others they are still missing.

Minimize chemical exposure: avoid any unnecessary potential contaminants, do not bring in or use air fresheners, candles, pesticides.

Find any water leaks, moisture on surfaces, mould and pest activity. Avoid dampness.

Ventilation and air cleaning. Special attention should be paid to ventilation because it has triple functions: it provides fresh air, removes accumulated pollutants or at least dilutes their concentrations and reduces air temperature. Fresh air demand is influenced by occupancy, activity, age and state of health of the occupants, size and function of the premises. CO₂ concentration is generally used as an indication of the efficiency of ventilation. 0.1% CO₂ concentration produces perception of stuffy air, 1% CO₂ causes discomfort/malaise, and 10% CO₂ is life threatening.

Generally the fresh air demand is 30 m³/hour per person. Based on the required floor space of 2 m²/child in the classroom and a ceiling height of 3 metres, the air demand of a child in the classroom is 6 m³. In order to fulfil the 30 m³/hour per person fresh air demand, the total volume of classroom air should be exchange 5 times per hour. Therefore thoroughly ventilate the classrooms before and after lessons, as well as



during breaks. Ensure proper ventilation of other rooms (corridors, cabinets, gyms), too.

Act immediately if any ventilation equipment breaks down. Clean the classrooms after the lessons: use wet cleaning practices for the floor and furniture, undust the rooms and furniture every day. The best solution is the use of wet vacuum cleaners with HEPA filters.

F. Specific actions aimed at reducing the health risks due to indoor chemical pollutants

Management of improving indoor air quality in schools can be successfully operated by a well designed and organized **action plan**. The action plan is based on the assessment of the current state of the school environment and on the identification of the problems. The action plan can only be fulfilled if there is a supportive legislation, group of public health experts, supportive school management, intersectoral cooperation and financial background. Some of the action can be carried out by using structural (e.g. EU) funds, some other programmes can be incorporated in the plans of regular maintenance of the school building, but some practical actions can be done without money like ventilation of the classrooms by regular opening the windows.

The action plan includes issues of proactive operation (preventive maintenance activity on buildings and equipment, right and accurate cleaning procedures and practices complemented by awareness training of the school board and staff), reactive measures like immediate provision and correction of building and equipment breakdowns and investigation of all IAQ concerns/complaints to resolve problems, as well as carrying out compliance policy and action (cooperation with stakeholders and keeping all local, state regulations and standards relating to IAQ in schools).

An action plan should be adaptable to individual school needs, implementable at no cost / low cost, no specialized training is required, it is voluntary, on common sense basis.



If there is a general understanding that good IAQ is important for learning, and it enhances the learners' and teachers' productivity, IAQ teams can be established in the schools, including the teachers and the students, their parents, the school board, the administrative staff, the school nurse / physician and the school operators. Members of the IAQ team regularly check the checklist items, inspect the school, set priorities and share information with the respective partners. This procedure would result in better productivity of learners and teachers, quicker and more cost-effective response to problems, peaceful atmosphere for staff, learners and parents, reduction of upkeep cost and expenses for repairs.

Proposed action plans for school maintainers to lower the concentration of indoor air pollutants (after Guidelines for Indoor Air Hygiene in School Buildings Produced by the German Federal Environment Agency's Indoor Air Hygiene Commission, Berlin) (UBA, 2008).

At minor building and renovation works:

There are four aspects to be considered in relation to air hygiene prior to building and renovation work, in order to minimise later emissions: a) choice of materials; b) quantity of materials; c) monitoring of the progress and completion of the work; d) coordinating and monitoring the time frame.

ad a). Select suitable, dedicated furniture and cover materials, equip the rooms with interior equipment that does not contain formaldehyde, or as little as possible. If you plan to change the furniture of the classrooms, do it during the summer holiday. Ascertain that the furniture can be ventilated by keeping the windows completely open as long as possible. The high formaldehyde emissions of new furniture and coverings will drop off after 6-8 week ventilation. Ventilate the indoor areas during and after using products containing benzene and other volatile organic compounds (e.g. during painting/use of colours).

ad b). Buy and stock the products that are the sources of VOCs in the quantities to be spent immediately. Do not store products that are a source of VOCs in rooms where children stay.



ad c). On-site monitoring of building and renovation work is important to check whether the materials delivered comply with all quality requirements (including emissions behaviour), whether the chosen products are indeed being installed in the school building properly and in sufficient time, whether the working instructions and advice from the manufacturer are being followed, and whether adequate ventilation and evaporation time is being allowed when laying and fixing materials. Proper supervision of the work by a project manager or comparable expert familiar with the indoor air hygiene requirements is strongly advised.

ad d). The emission of VOCs and SVOCs from construction products and decorating materials can be considerably restricted, but not completely avoided. Indoor air is almost always additionally contaminated by VOCs immediately after building and renovation work. For this reason a certain length of time should be scheduled (this can take from one to several weeks, depending on the extent and type of renovation work) for the VOCs to escape before using the rooms again. Minor building works and renovations should be scheduled for the beginning of the school holidays, so that most of the components have already been released from the materials before the room is used again. While the offgassing of the substances is taking place there must be intensive ventilation.

If hot water pipes and radiators are newly painted, it is a good idea to run the heating system briefly when the paint is dry and nobody is in the room. This will allow compounds occurring in the paint layer at higher temperatures, generating unpleasant odours and irritations to be released from the paint layer in good time. Once the construction and renovation work is complete the entire building should be intensively cleaned. Cleaning with water and the most thorough possible removal of all dust deposits is strongly advised.

At cleaning:

All areas of the building should be easily cleaned. Cleanliness and hygiene are of particular importance in school buildings because the environment in which children are educated influences their health as well as their own perception of hygiene and their hygienic habits.



Classrooms should be cleaned every day by washing the floor properly and wiping tabletops with a damp cloth.

Carpeting in classrooms and teaching areas can pose a hygiene problem, as it is more difficult to clean than hard, washable floors. If carpets have to be renewed, they should be replaced with hard, washable flooring. Carpeting, which is laid in some schools for reasons of noise control, should also be properly vacuumed at least every other day, if possible with a vacuum cleaner fitted with a HEPA filter.

Linoleum has environmental advantages owing to its natural constituents. There is a distinction between cleaning linoleum after installation, or initial cleaning, maintenance cleaning by washing and wiping with a damp mop or using a floor cleaner, and deep cleaning followed by replenishing the protective finish. When selecting cleaning and maintenance products for linoleum those with a pH value of pH9 and above should be avoided because, these products may aggressively attack the natural materials of linoleum and can destroy the surface. For this reason soft soap may not be used, either.

Sanitary areas and washrooms including changing rooms in school buildings are of particular importance in terms of hygiene. Here thorough cleaning must be undertaken at least once a day and floors scrubbed regularly. Tiled walls and floors are ideal for this. Cleaning procedures involving disinfectants are generally not necessary in sanitary areas to prevent infection, but can be appropriate in the event of contamination of surfaces by faeces, vomit, etc., or if notifiable infectious diseases occur. In this latter case the health agency will organise suitable measures.

Over and above the maintenance cleaning, deep cleaning, special cleaning and cleaning of glass as well as care programmes should be carried out to ensure adequate hygiene standards. After deep cleaning additional protective care measures may be required, depending on the type, composition and condition of the surfaces. A thorough cleaning and care programme should be carried out in all areas of the school at least once a year. This involves not only cleaning the floors, but also the furniture and other pieces of equipment.



For both the routine cleaning and the thorough cleaning and care only cleaning products posing no risk to health should be used. If different cleaning products are used, it should be checked that the products do not neutralise each other's effect and no substances harmful to health are produced by mixing them together.

Ventilation

A reduction of air pollution in classrooms cannot be guaranteed through cleaning alone, reduction of existing sources of emissions and regular ventilation are equally important. The most important function of ventilation is to renew the indoor air by extracting impurities in the form of gas and dust and the metabolic products from humans (odours, carbon dioxide, water vapour) and to supply fresh air from outside.

School buildings have generally been designed and built in such a way that natural or "fresh air" ventilation through windows would be sufficient. (All windows should be easily openable!). However, in unfavourable locations (e.g. considerable noise pollution from the vicinity or high air pollution) installation of ventilation systems may be necessary. In addition, special extraction systems are also required for laboratories which experiments producing high levels of smoke.

When using ventilation via windows or air vents in external walls it is important to reduce the possible high noise levels from outside (e.g. traffic noise, aircraft noise). Installation of highly sound-absorbent ventilating windows or sound-insulated ventilation ducts may help in this case.

To prevent the rooms from overheating through solar irradiance, windows should not be larger than necessary for appropriate day lighting without glare. Where the proportion of glass in the façade exceeds 50 % all façades, with the exception of those facing north, require sunshading.

In case of natural ventilation through wide-open windows the air-change rate is around 10-20/h. The necessary air exchange of around 25 to 30 m³/h per person cannot be achieved through natural ventilation with closed windows (known as window gap ventilation), but only by regularly opening the windows wide for short periods ("intensive ventilation" up to 10 minutes). Even more effective (if possible) is



cross-ventilation via windows opposite each other. All windows in teaching areas should be opened wide (intensive ventilation, cross-ventilation) at least during every break and at the beginning and at the end of the school day during term-time.

In winter heat inevitably escapes during ventilation. The reserve capacity of the heating system must allow the rooms to warm up again quickly after ventilation.

If natural ventilation is not adequate to create or maintain hygienically ideal air quality during lessons as well, mechanical ventilation options can be installed to ensure sufficient air replacement even with the windows closed. High levels of noise and other emissions outside can also make mechanical ventilation systems necessary. If systems of this sort are installed, regular servicing must be guaranteed for hygienic reasons.

G. Action plan for combatting climate change effects

The external thermal insulation of schools not only reduces the heat loss in winter but also prevents the heat loss and cooling of the classrooms at night in the summer. Therefore, it is necessary to solve the night ventilation by keeping the windows open in tilted position and propping them against possible stormy winds.

To reduce the overheating of classrooms in the daytime, install outdoor shades. It is advisable not only to shade the windows but also the south-facing walls.

“Greening” reduces warming up of the walls - in addition to humidifying, filtering and refreshing the air. Plants use only a small fraction of the amount of water they absorb for their physiological processes, they evaporate the rest. The evaporating water removes heat from the air and therefore reduces its temperature. Green walls can be realized at relatively low cost with running plants. If the wall has sufficient load capacity, some plants (such as wild grapes) can be run directly on the wall, but many plants (different vine species, Chinese purple acacia, honeysuckle, clematis, rambler rose etc.) can also be run on different self-supporting or wall-mounted support



systems. Large canopy trees planted around the school can also reduce warming up and purify the air.

Drinking fountains in the corridor and in the yard can be realized at a relatively low cost with proper planning and implementation.

H. Conclusion

Good IAQ is the guarantee of comfort, health and safety. It is especially important in the school because growing children are very sensitive to hazardous chemicals.

Exposure to poor IAQ in school can keep back learner's task performance. Materials with low emission, adequate ventilation and cleaning methods, adequate temperature, humidity and mould control are essential components of healthy school environment.

References

1. ENVIE Project (2008) Final Activity Report of the ENVIE Project (Co-ordination Action on Indoor Air Quality and Health Effects):
<https://cordis.europa.eu/result/rcn/49589/en>
2. PARMA Declaration (2010):
http://www.euro.who.int/__data/assets/pdf_file/0011/78608/E93618.pdf
3. SEARCH Study (2013)
http://documents.rec.org/publications/SearchMakingSchoolsHealthy_Web_Dec2013.pdf
4. UBA (2008): Guidelines for Indoor Air Hygiene in School Buildings Produced by the German Federal Environment Agency's Indoor Air Hygiene Commission, Berlin, 2008
<http://www.umweltbundesamt.de/index-e.htm>
5. WHO Air Quality Guideline for Europe (2nd ed.). WHO regional publications. European series ; No. 91, 2000.