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To be or not to be regulated: indoor air pollution in Turkish schools

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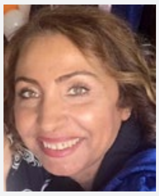

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Introduction

The Union of Chambers and Commodity Exchanges of Türkiye (TOBB), Turkish Climatization Assembly, Indoor Air Quality Committee established a Limit Values Working Group (LVWG) consisting of researchers who meet the criteria of having publications on indoor air pollution in internationally respected journals in the field of indoor air quality and having knowledge about the health effects of air pollutants. The task of the working group was to cover a wide list of pollutants to recommend pollutant limit values that would be applicable to indoor air quality in schools by reviewing the relevant literature and limit and guide values. For this purpose, group members identified the indoor air pollutants that should be included in the study, conducted a literature review within the predetermined methods and constraints, and presented their compilations and limit value recommendations (Sofuoglu et al., 2023). After discussion of each recommended limit value, finalized as a LVWG decision, which were then presented to climatization sector stakeholders in a two-day workshop (19-21 September 2023, Ankara, Türkiye) entitled International Indoor Air Quality of Schools and Student Living Areas Summit.

Indoor air pollutants examined by LVWG cover inorganic and organic gases, particulate matter (PM) and biological pollutants. In this context, an evaluation was made for a total of 19 pollutants / pollutant groups, which included carbon dioxide, carbon monoxide, nitrogen dioxide, ozone, radon, volatile organic compounds, formaldehyde, trihalomethanes, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, brominated flame retardants, organophosphate esters, phthalate esters, PM, bioaerosols (bacteria, fungi, viruses), microbial pollutants and allergens. A recommendation was made by the working group for 11 pollutants/groups (CO_2, CO, NO_2, O_3, radon, VOC, formaldehyde, trihalomethanes, PM, bacteria, fungi) whereas no recommendation was made for 8 pollutants/groups (polycyclic aromatic hydrocarbons, polychlorinated biphenyls, brominated flame retardants, organophosphate esters, phthalate esters, microbiological contaminants and allergens) based on the existing knowledge, that is, indoor air pollutant levels, pollutant health effects, if there is a sufficient scientific basis between pollutant levels and health effects, the time students spend in schools, and the prevalence of existing limit/guideline values and the health effects that they are based on.

Reviewed Pollutants

Nitrogen dioxide, carbon monoxide, and ozone

Nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3), are discussed together because their source is generally the outdoor air and they have been regulated by ambient air quality legislation for a long time. Therefore, the health effects are well known, and the limit values in the legislations are based on health effects. Of these gaseous pollutants, NO_2, and CO mainly emitted from motor vehicles in an urban setting among other combustion sources. O_3 is a secondary pollutant that at ground level forms as a result of atmospheric chemical reactions of traffic emissions in the presence of sunlight, therefore, its formation is the highest in traffic-dense areas. For these reasons, children are exposed to high levels of all three pollutants in urban schools, especially in high-traffic areas. Due to the health effects stated below, it was deemed appropriate to recommend limit values for all three pollutants.

There is a possible cause-effect relationship between short-term exposure to CO at typical outdoor concentration levels and cardiovascular, nervous system, respiratory tract effects, and therefore mortality, while there is some evidence suggesting that there may be a cause-effect relationship between long-term exposure and effects on the nervous system, and birth and development. Although there is a cause-effect relationship between short-term NO_2 exposure and respiratory effects, these effects are considered probable for long-term exposure. It has been evaluated that there is some evidence indicating that there may be a cause-effect relationship between short-term exposure and cardiovascular effects and total mortality, and between long-term exposure and cardiovascular effects and diabetes, birth-related effects, total mortality and cancer, but further research results are needed due to uncertainties.

During respiration, O_3 reacts with lipids, proteins and antioxidants in the fluid covering the inner surface of the respiratory tract, and causes the formation of secondary oxidation products; thus, causing effects on the respiratory tract. There is a cause-effect relationship between these effects and short-term O_3 exposure. For long-term exposure, a possible cause-effect relationship was characterized for the relationship between effects on the respiratory tract and O_3 exposure. There are also health effects for which there is some evidence to suggest a cause-effect relationship with short-term and long-term exposures, but are considered insufficient due to uncertainties: metabolic, cardiovascular and nervous system diseases, reproductive / developmental diseases and mortality.

Carbon dioxide

Respiration is the main source of carbon dioxide in indoor environments. Its indoor air concentrations may significantly increase in crowded places such as schools. CO_2 was not considered an indoor air pollutant until recently and was used as an indicator of ventilation effectiveness. At levels observed in classrooms, health effects are in the form of symptoms of sick building syndrome such as headaches and fatigue, while cognitive effects and reduced academic performance are plausible. It was deemed necessary to find a limit value for CO_2 both as an indicator of ventilation effectiveness and because of its cognitive effects.

Radon

Radon has been studied for many years and its health effects are well known. It is a gas regulated by legislation in Türkiye in homes and workplaces. According to both the data from World Health Organization and the Ministry of Health, smoking ranks first among the main causes of lung cancer, while cancers caused by the effects of radon gas rank second. Based on the data of the Ministry of Health, 3 – 15% of lung cancers in our country are caused by radon gas. According to the research, the number of deaths due to the effects of radon gas in our country has exceeded 2,300 people annually. It is stated that an increase in the long-term average radon concentration leads to an increase in the risk of lung cancer, and the rate is 25 times higher in tobacco smokers. However, this is not limited to tobacco users; it is known to be higher in those exposed to secondary tobacco smoke or to PM in indoor environments where radon is present. Meanwhile, radon pollution is more common in radon-contaminated areas due to its geological origin. It was found important to recommend a limit value to be applicable in these regions.

Volatile organic compounds

Volatile Organic Compounds (VOCs), which include a wide range of compounds, are organic vapours that can cause various adverse health effects that volatilize at room temperatures, especially cancer, as a result of long and short-term exposure. They are very important pollutants that impact the indoor air quality of homes, public buildings, offices, and indoor environments, including schools, and collectively threaten human health with such as building related symptoms, especially of sensitive individuals in the short term, and as a result of continuous exposure with chronic-toxic and carcinogenic health effects of many building residents. VOCs are present in indoor air as a result of volatilization from paints, varnishes, and polishes, and various building materials such as wood, chipboard and MDF, carpets and floor coverings, various electronic devices such as printers/photocopiers, and chemicals used as solvents in personal and home care products. VOCs may also be at very high levels in outdoor air due to urban and industrial emissions. Effects ranging from symptoms such as burning in the eyes and throat, distraction, dizziness, nausea, weakness, vomiting, as well as diseases may occur as a result of long and short-term exposure to many VOCs. Benzene, formaldehyde, and trichloroethylene, for instance, are known carcinogens. For many VOCs, especially benzene, WHO, the International Agency for Research on Cancer (IARC), and the American Occupational Safety and Health Agency (OSHA) recommend indoor air limit values to minimize its adverse chronic-toxic and carcinogenic effects. Consequently, it is considered crucial to recommend limit values for VOCs with carcinogenic and toxic effects, for schools where school-age children, a susceptible population group, spend a significant part of their daily lives.

Formaldehyde

Although well known for a long time, formaldehyde is still one of the most important indoor air pollutants. The main sources of formaldehyde in non-smoking indoor environments include building construction materials, furniture, paints, cosmetic products, disinfectants, paper products, pressed wood and fabric products. Additionally, factors such as building age, temperature, humidity level, air exchange rate, and season are determining variables. There are standards to limit emissions from building and furnishing materials and consumer products. However, a limit is still needed to keep indoor exposures below safe levels. The main route of exposure to formaldehyde is through inhalation. The effects of formaldehyde on humans include all, i.e., acute, chronic-toxic (non-cancer), and carcinogenic effects reported by numerous case-control and cohort studies, and reviews. The most important evaluation in terms of health effects is the classification of formaldehyde by the IARC / WHO as a “Group-1 human-carcinogenic substance” (nasopharyngeal cancer and myeloid leukemia are the most commonly observed types). Therefore, it is very important to recommend an indoor air limit value for schools.

Disinfection by-products

The purpose of disinfection applied to water used in swimming pools is to prevent swimmers from being exposed to waterborne infections caused by microbial pathogens originating from the water that feeds the pool water or from swimmers in the water. Disinfectants dosed into water to prevent microbial activity react with organic and nitrogenous compounds (urine, sweat, hygiene and cosmetic products, etc.) in swimming pool water and form disinfection by-products (DBPs). Generally chlorinated disinfectants are preferred. Trihalomethanes (THMs; chloroform, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform) are known as the most dominant group of DBPs. THM intake occurs through dermal contact, accidental oral ingestion, and inhalation exposures. Because THMs are volatile compounds, volatilization from the pool water results in their accumulation in the indoor air if air exchange rate is not sufficient for replenishment with fresh air. Research has identified links between exposure to THMs and a variety of human health effects, from respiratory irritation to different types of cancer. Studies conducted by WHO and scientists indicate that inhalation exposure may be much higher than accidental ingestion or skin contact. Various countries have issued guidelines for the safety of swimming pools and similar recreational aquatic environments, including standards for minimizing microbial and disinfection by-product hazards, taking the WHO assessment into account. However, there is no limit value for DBPs in indoor air around the world other than the value determined for indoor pools in one country. In light of the available information, a THM limit value(s) for indoor pools would be significantly beneficial for the health of swimmers, coaches and staff, especially for children.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds composed of two or more fused aromatic rings of carbon and hydrogen. PAHs may be considered as persistent organic pollutants (POPs) due to their ability to resist environmental degradation through biological, chemical, and photolytic processes. PAHs occur as products of incomplete combustion and their major anthropogenic sources include emissions from traffic, coal combustion processes, power plants, waste treatment, biomass and wood combustion. PAHs in indoor air arise from activities such as smoking, cooking, burning various fuels, candle burning, building materials, and infiltration of outdoor air. For the school environment, unlike other indoor sources, the use of petroleum-based artistic materials (paints, crayons and clays), burning candles (birthday celebrations), and cleaning products may contribute. Sixteen PAH compounds have been included in the list of priority pollutants by the European Commission and the United States Environmental Protection Agency (USEPA) due to their mutagenic and potentially carcinogenic properties. Additional 10 compounds have been identified as possible carcinogens by IARC. Unless there is a specific source indoors, the main source of PAH compounds is outdoor air. Cooking or heating activities at home and production-related activities at workplaces show that there are sources of PAH compounds in the indoor environment as well as the outdoor air. However, for schools, these activities are very limited compared to the outdoor air. It is considered important to recommend limit values for these compounds due to their carcinogenic and chronic-toxic effects, but having an outdoor air quality standard is deemed currently sufficient.

Phthalic acid esters

Phthalates (Phthalic acid esters (PAE)) are widely used as plasticizers and to give color and fragrance to cosmetic products, toys, food packages, electronic items such as computers and smart boards, PVC flooring, clothes, home textile products, stationery, detergents, solvents, and construction materials. Because phthalates do not form covalent bonds with the material to which they are added and due to their physicochemical properties, they volatilize into indoor air, adsorb to dust and particulate matter, which prolong their presence. Phthalates are among the most common environmental pollutants due to their use in industrial applications of 6-8 million tons per year on a global scale, their accumulation in fatty tissue, and bioaccumulation in the food chain. Routes of human exposure to phthalates include nutrition, inhalation, dermal absorption, and accidental dust ingestion. Indoor exposure via these three pathways is estimated to be higher than dietary exposure for some phthalates. Although there is insufficient evidence that phthalates are carcinogenic in humans, studies on animals show that phthalate exposure during pregnancy causes various developmental and reproductive system disorders. Phthalates are in the group of "endocrine disrupting chemicals" and positive associations have been found between asthma and allergy symptoms in humans and negative associations between exposure and intelligence levels observed from the child's behaviour. The fact that there are limit values for phthalates in building construction materials used in schools in our country, indoor materials such as classroom desks and boards, as well as textile products, cosmetics and stationery materials help in exposure mitigation. However, the amount of phthalate-containing materials, room size, and air exchange rate directly affect indoor gas and dust-phase phthalate levels. Indoor dust phthalate levels are also related to cleaning frequency of dust accumulating surfaces. For this reason, in order to increase the indoor air quality in classrooms, the amount of products containing phthalates and the frequency of cleaning the classroom are important.

Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) have been produced since the early 1930s, first in the United States and then in many countries around the world. PCBs are stable molecules resistant to hydrolysis, oxidation and temperature changes, they show excellent insulating properties and are difficult to degrade, and they have long half-lives in the environment. Therefore, they have been used in sealants, coatings, as stabilizing additives in PVC plastics, paints, adhesives, lubricants, and joint fillers/sealants. Restriction and prohibition regulations have been made in various countries since the 1970s due to their environmental occurrence in regions far from their sources and the strong biomagnification of highly-chlorinated PCBs in aquatic and terrestrial food chains. The international convention on Persistent Organic Pollutants (POPs), declared in Stockholm in 2001, aims to eliminate PCBs worldwide by 2028. PCBs have not been produced intentionally then for a long time, but due to their physicochemical properties, they still are released into the ambient air from the PCB-containing materials and equipment. There is clear evidence that PCBs cause cancer in animals, and they have been classified as probable human carcinogens. Human and animal data provide evidence that PCBs have significant adverse effects on the immune system, reproductive system, nervous system, and endocrine system. Due to the ubiquity of PCBs in the environment, humans are exposed to PCBs through ingestion, inhalation, and dermal contact. Ingestion has long been identified as the primary route of exposure, but inhalation stands out as an important route of exposure for children.

Brominated flame retardants

Brominated organic compounds have been added to a wide variety of consumer products as flame retardants. Flame retardants are found in products such as foams and plastics used in textiles, electrical and electronic equipment (computers, monitors, printers and TVs), furniture and flooring, construction and refrigeration products, and paints. Polybrominated diphenyl ethers (PBDEs; Penta-BDE, Octa-BDE and Deca-BDE), hexabromobenzene (HBB), hexabromocyclododecane (HBCD), and 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (TBB) are such substances. Due to their toxic effects as a result of their persistence and bioaccumulation potential, penta-, octa-, and deca-BDE, HBB, and HBCD are included in the Stockholm Convention, imposing restrictions on their production and use. Nevertheless, they are ubiquitous in the environment and have been found in the indoor environments due to the long lifespan of materials containing these components. Studies have shown that BFRs are largely found in indoor dust. Their health effects include changes in thyroid function, diabetes, neurobehavioral, developmental and reproductive disorders while there is no environmental limit value, except for restrictions on production and use.

After the restrictions on the above mentioned compounds, the need for flame retardants in the industry led to employment of alternative substances. PBDE substitutes have begun to be used under the name of novel brominated flame retardants (NBFRs), e.g. 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (TBB), bis(2-ethylhexyl) 3,4,5,6-tetrabromophthalate (TBPH), Tetrabromobisphenol A (TBBPA) (tetrabromobisphenol A-bis(2,3-dibromopropylether) (TBBPA-DBPE), and hexachlorocyclopentadienyl-dibromocyclooctane (HCDBCO). Limited research indicates that NBFRs may also have the potential for bioaccumulation and toxicity. Recent animal studies have indicated that many of them may be EDCs in rats, and cause altered gene expression and transcriptional response, disruption of the thyroid axis, and reduced fertility in zebrafish. Nevertheless, there is a lack of sufficient data on the levels of new brominated flame retardants in the indoor environment and their health effects.

Organophosphate esters

Organophosphate esters (OPEs) are a group of alternative fire retardants. It is estimated that their production has increased significantly in the last 10 years. In general, chlorinated organophosphate esters are used as flame retardants, while non-chlorinated ones are added to products as plasticizers. Since OPEs used as additives are not covalently bonded with the polymeric material, they may be released into the environment through volatilization, leakage and abrasion, and can be directly transferred to dust by contact. Their presence in biota and breast milk indicates that these compounds also bioaccumulate by entering the food chain. Although there are limited toxicological and epidemiological studies on the risks caused by OPEs, some of them have been reported to be mutagenic, carcinogenic and neurotoxic, and also have adverse effects on the developmental and reproductive systems. Compared to adults, children are still developing and are more likely to be exposed to these chemicals at higher levels because they have lower body weight and frequently put their hands or materials such as pencils and erasers into their mouth. For this reason, in order to control OPE levels in the indoor air in schools, it is necessary to control the amount of additives in products containing OPE, limit their amounts, and pay attention to the frequency of cleaning of the classroom.

Particulate Matter

$PM_{2.5}$ and PM_{10} are generally the monitored size fractions in schools while measurements are mostly carried out in classrooms. Studies on PM_1 and particle count concentrations are limited in the literature. PM levels in schools are affected by factors such as location of the school, its proximity to traffic, number of students, proximity of the classroom to the cafeteria, number of classroom windows, frequency of classroom cleaning, and ventilation type and rate, but most of the studies have emphasized that outdoor air is the main source of PM in classrooms. Additionally, the movement of children is found to be important as it results outdoor-to-indoor transport and re-entrainment of settled dust into indoor air especially significant for larger particles, i.e. PM_{10}, with decreasing age of children. PM is a well-known contaminant categorized as a carcinogen by WHO, and it is an important component of indoor air pollution in schools that have adverse effects on children's health. PM exposure is associated with diseases such as asthma, allergic diseases, acute and chronic respiratory diseases, changes in blood pressure and lung functions, obesity and slowing of cognitive development in children. Therefore, limit values should be recommended for PM.

Bioaerosols

Bacteria can survive and grow on their own almost anywhere (in soil, in water, and in our bodies). The main sources of bacteria in indoor air are human beings and other organisms, human activities, building materials, and outdoor air. Bacteria have a wide range of health effects, from mild symptoms such as coughing and sneezing to serious infections and diseases that could result in death. Although the observed health effects depending on the concentration and species composition in indoor environments generally appear as respiratory and skin diseases, it has also been determined that sick building syndrome is among others. Exposure to airborne bacteria may occur through breathing, speaking, coughing, sneezing, etc. of the infected organism. The size of the droplets released from the mouth and nose into the air and the movement of the air in the room are the two main determining variables for airborne duration, that determines inhalation exposure. Temperature and humidity are critical for the reproduction of bacteria. Various diseases such as Legionella infection, tuberculosis, and plague have been described that are associated with exposure to various bacteria that are known to cause disease and observed in indoor air. Therefore, it was considered important to have a limit value for bacteria.

While environmental yeast and mould species that generally live in soil do not usually cause infection in most healthy people, some environmental fungi can multiply rapidly through "spores" (particles that can enter our bodies through the lungs or skin) and cause damage to many organs, especially in people with weakened immune systems. The capacity of at least 700 fungal species to produce toxic compounds triggers allergic reactions and even potentially harms human health as direct infectious agents. The release of spores by moulds in buildings that are not properly designed, constructed and maintained can be the primary source of a number of emerging diseases and sick building syndrome. Fungal spores can be released from sources such as mouldy food items, walls, potted and indoor plants, furniture padding, and pets and their bedding. Allergic, toxic and infectious effects may occur with exposure to fungi. Although the pathogenic role of moulds is known, a clear dose/effect threshold has not been determined. The development of allergic diseases varies among individuals and is likely influenced by history of exposure from early childhood, genetic factors, and/or exposure to fungi in occupational and other indoor environments. It was considered important to have a limit value for fungi, similar to bacteria.

Bacterial endotoxins, fungal mycotoxins, peptidoglycans, beta (1→3)-glucans, viruses, high molecular weight allergens, pollens, algae, and protozoa are among the other microbiological pollutants for indoor air quality. The presence and concentration of microbiological pollutants may vary depending on conditions and activities in a microenvironment, such as the number of people and pets, climatic characteristics, building features, furniture, and food. Although it is known that exposure to these pollutants may cause health effects similar to those associated with exposure to bacteria and fungi, there are not sufficient information to determine dose-effect relationships. Further research is needed on the sensitivity of children in different age groups to microbial contaminants, such as defining standard protocols for sampling and determining appropriate diagnostic testing methods for diseases caused by biopollutants. However, there are countries where the current knowledge of endotoxin is considered sufficient, and it would be beneficial to have a limit value.

Conclusion

As a result, if there is a sufficient scientific basis between the existing knowledge, that is, indoor air pollutant levels, pollutant health effects, time period students spend in schools, prevalence of existing limit/guideline values and the health effects that they are based on, a recommendation is made by the group member(s) for a pollutant / pollutant group. The recommendation(s) were discussed and a LVWG's decision was made. Indoor air limit values for Turkish schools are recommended for 11 pollutants/groups (CO_2, CO, NO_2, O_3, radon, VOC, formaldehyde, trihalomethanes, PM, bacteria, fungi) and not recommended for 8 pollutant groups (polycyclic aromatic hydrocarbons, polychlorinated biphenyls, brominated flame retardants, organophosphate esters, phthalate esters, microbiological contaminants and allergens). The compiled information on all of the pollutants is available in Sofuoglu et al. (2023). Although the book is in Turkish, a shortened version is to be submitted to a scientific journal in English.

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