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Review article

Children's well-being at schools: Impact of climatic conditions and air pollution

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ABSTRACT

Human civilization is currently facing two particular challenges: population growth with a strong trend towards urbanization and climate change. The latter is now no longer seriously questioned. The primary concern is to limit anthropogenic climate change and to adapt our societies to its effects. Schools are a key part of the structure of our societies. If future generations are to take control of the manifold global problems, we have to offer our children the best possible infrastructure for their education: not only in terms of the didactic concepts, but also with regard to the climatic conditions in the school environment. Between the ages of 6 and 19, children spend up to 8 h a day in classrooms. The conditions are, however, often inacceptable and regardless of the geographic situation, all the current studies report similar problems: classrooms being too small for the high number of school children, poor ventilation concepts, considerable outdoor air pollution and strong sources of indoor air pollution. There have been discussions about a beneficial and healthy air quality in classrooms for many years now and in recent years extensive studies have been carried out worldwide. The problems have been clearly outlined on a scientific level and there are prudent and feasible concepts to improve the situation. The growing number of publications also highlights the importance of this subject. High carbon dioxide concentrations in classrooms, which indicate poor ventilation conditions, and the increasing particle matter in urban outdoor air have, in particular, been identified as primary causes of poor indoor air quality in schools. Despite this, the conditions in most schools continue to be in need of improvement. There are many reasons for this. In some cases, the local administrative bodies do not have the budgets required to address such concerns, in other cases regulations and laws stand in contradiction to the demands for better indoor air quality, and sometimes the problems are simply ignored.
This review summarizes the current results and knowledge gained from the scientific literature on air quality in classrooms. Possible scenarios for the future are discussed and guideline values proposed which can serve to help authorities, government organizations and commissions improve the situation on a global level.

Contents

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1. Introduction

People are exposed to ambient air pollutants everyday regardless of their locations and activities. The extent of their exposure depends on a number of factors, including local environmental characteristics and an individual's lifestyle. However, air pollution in general - and particularly urban air pollution - is becoming a global problem, as recent smog events in Beijing, Delhi, Rome, Milan, Barcelona and other metropoles have shown. In 2014, as much as 54% of world population lived in cities, in comparison to 34% in 1960, and it is estimated that the trend of urban population growth will continue in the future (WHO, 2015). Under the primary assumption that all particles are equally toxic, the global mortality due to the combined effect of ambient air pollution in terms of $PM_{2.5}$ and ozone (O_3) in 2010 was estimated as 3.3 million by Lelieveld et al. (2015).

Changes over recent decades in outdoor concentrations of air pollutants are well documented in the literature. However, the impacts of air pollution on an individual's health relate to the total personal exposure (outdoor and indoor). The relevance of indoor air quality (IAQ) for exposure assessments stems from the fact that individuals are exposed to different concentrations of air pollutants as they move to and from different outdoor and indoor locations (Buonanno et al., 2015). As a result, a more efficient way to protect the population from health risks caused by air pollution should be based on exposure rather than estimates of ambient air pollutant concentrations (Morawska et al., 2013).

The continuing change in climate and ambient air pollutant concentrations will have a significant impact on the quality of indoor air and the way people live in all regions of the world (IOM, 2011). Stronger variations in temperature and humidity, sometimes under extreme weather conditions, combined with growing contamination of outdoor air with gaseous substances and particulate matter (PM) will more than ever before pose the question of how indoor spaces can maintain good IAQ. Because outdoor air pollutant concentrations infiltrate indoors, child exposure in classrooms is to a large degree affected by outdoor emissions, and as a result, school classrooms will be especially affected by these developments. Classrooms generally accommodate a large number of people and therefore require a certain air exchange to maintain low levels of carbon dioxide (CO_2) and other pollutants to allow children to perform well in school (Canha et al., 2015). CO_2 is usually considered as a reference parameter for IAQ, because high CO_2 concentrations indicate poor ventilation conditions and the possible accumulation of other pollutants in indoor air. However, teaching staff and school children usually control ventilation by thermal comfort rather than air quality (Griffiths and Eftekhari, 2008). In most cases, ventilation is achieved through direct exchange with the outdoor air rather than by means of ventilation and air conditioning systems. The result is that due to rising outdoor levels of temperature, humidity, CO_2, organic and inorganic compounds and airborne particles it will become increasingly difficult to achieve a room climate suitable for learning and teaching.

At present, the amount of data available regarding particulate matter mass concentrations (PM_{10}, $PM_{2.5}$, PM_1), ultrafine particles (UFP, measured as particle number concentration PNC) and gas phase pollutants (NO_2, O_3, CO, CO_2, very volatile, volatile and semi volatile organic compounds (VVOCs, VOCs and SVOCs)) found in school indoor air is not as voluminous as that available for outdoor air, or even for other indoor microenvironments. This is mainly linked to technical difficulties in indoor air monitoring in classrooms, which should be minimally invasive. However, monitoring and ensuring the necessary IAQ is paramount to guaranteeing optimal educational conditions (Goyal and Khare, 2011; Turunen et al., 2014). In particular, evaluating the effects of school ventilation on children's indoor exposure is especially recommended (Raysoni et al., 2013).

In this review, we report the current findings on the effect of climatic parameters and air pollution on children's well-being and health, resilience to withstand the effects of climate change on urban school environments, and any associated consequences. As shown in Fig. 1, the school environment is complex. Based on the evaluation of available literature (see chapters below), thermal comfort, air pollution sources, school building characteristics and mobility of the school children are

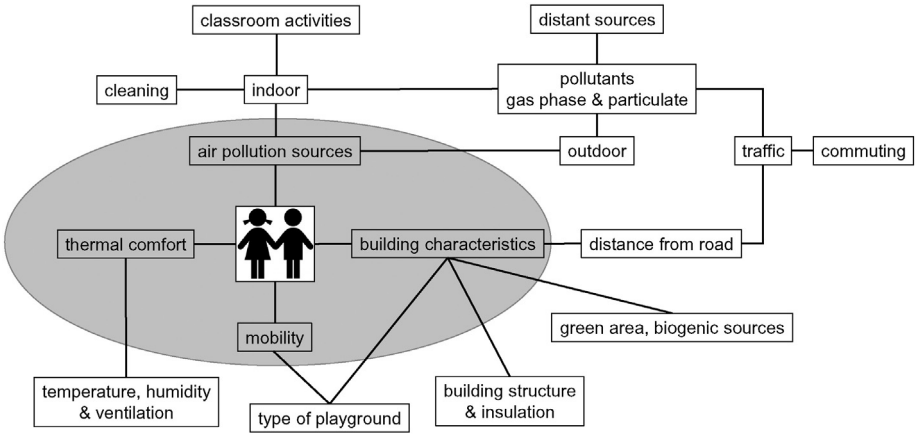

Fig. 1. Schematic representation of factors and linkages with possible impact on the indoor air quality in classrooms. Thermal comfort, air pollution sources, school building characteristics and mobility of the school children are considered as the primary factors (grey area). Influencing variables of major importance are also provided.