Building and Environment 94 (2015) 569–579

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Assessment of school building air quality in a desert climate

Jamal Al-Hubail, Abdul-Salam Al-Temeemi*

College of Technological Studies, Public Authority for Applied Education and Training, P.O. Box 42325, Shuwaikh 70654, Kuwait

ARTICLE INFO

Article history:
Received 17 July 2015
Received in revised form
22 October 2015
Accepted 23 October 2015
Available online 28 October 2015

Keywords:
Air pollution
Kuwait
Indoor air quality
Volatile organic compound
Building environment
Particular matter
Classroom environment
Indoor air pollution
Sick building syndrome

ABSTRACT

This study, to our knowledge, presents the first indoor data for a range of major air pollutants in school buildings in various locations in the State of Kuwait. Indoor air testing was performed within secondary schools over a 7-month period and sampling was conducted on a spot basis during normal school hours. As part of this program, samplers were deployed in student occupied classrooms at 46 selected buildings and monitored for air quality. The collected data was then compared to various international standards and guidelines relevant to the indoor environment. The results indicate that PM10 concentrations in 54% of the schools and CO_2 in 24% of the schools exceed allowable standards during school hours that may cause potential health hazards to exposed occupants. Other pollution parameters measured in this study conformed to the standards.

The results of a questionnaire given to the student occupants showed significant correlations between indoor PM10 and CO_2 concentrations and some health ailments suffered by the students.

Ultimately, the data in this study will serve as a baseline for comparison with future air quality assessment in buildings. In addition, recommendations are proposed in order to control the air quality problem in the identified schools, which may be useful information for policy makers, health related officials, academicians and scientists.

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1. Introduction

Indoor air quality (IAQ) has been the subject of numerous studies due to an increasing concern scientists have on the effects of indoor air pollution on health, mainly as people typically inhabit more time indoors than outdoors [1–5]. Indoor air pollution is a combination of the contribution of outdoor sources and indoor sources. In some cases, outdoor pollution can contribute to the indoor levels in buildings located near highways or industrial areas. Outdoor sources enter buildings through windows, doors, and ventilation systems, affecting the indoor air quality. Many studies [6–8] have demonstrated that industrial emissions are the major sources of pollutants, such as ambient, volatile organic compounds (VOCs), while the sources of VOCs are quite numerous within any indoor environment. These sources initiate from building and construction materials and furnishings, building occupants and activities, poor building design, and poor maintenance. Indoor pollutants may also emanate from the infiltration of outdoor pollutants such as dust, soil and internally from smoking, building and furniture materials, consumer products, building renovation or remodeling. Studies by the U.S. Environmental Protective Agency (EPA) [9] reveal that indoor levels of pollutants may sometimes be more than 100 times higher than outdoor levels.

Additionally, certain weather conditions can contribute to indoor pollutants. In a countries frequented by sandstorms, re-suspension of dust due to movement of people has been found to be a major source of particulate matter (PM) exposure [10,11].

Educational facilities are among the indoor premises suspected of high pollutant concentrations, more serious than in other categories of buildings, due to higher occupant density and due to increased movement of students during breaks and when changing classrooms. Some studies have [12–14] identified re-suspension arising from classroom activity as a cause of elevated PM10 concentrations and found that most of the particles were dust brought in by shoes. Other studies [15] have shown that the PM concentrations measured inside classrooms can be higher than the corresponding outdoor concentrations and concentrations measured inside residences.

Exhaust from idling vehicles on school premises can also directly affect occupants in classrooms with improper ventilation facilities [16–18]. In 1999, indoor air quality (IAQ) was reported to

* Corresponding author.
E-mail addresses: jaalhubail@hotmail.com (J. Al-Hubail), temeemi@hotmail.com (A.-S. Al-Temeemi).

http://dx.doi.org/10.1016/j.buildenv.2015.10.013
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be substandard in about 20% of public schools in the United States, while ventilation was described as inadequate in about 25% of public schools [19]. Further studies [20,21] have also shown high contamination levels of carbon dioxide in classrooms.

The health problems owing to indoor air pollutants are more widespread than those caused by outdoor air pollutants since the exposed persons are closer to the source of indoor air pollutants. Long-term exposure to pollutants such as volatile organic compounds (VOC), particulate matter (PM), CO_2 and other gases in indoor environments may cause a number of health ailments such as dizziness, asthma, and respiratory diseases. Other health effects may show up years after having been exposed or only after long or recurring exposure.

Exposure to PM in particular has been shown by epidemiological research to be linked with a wide range of health ailments [22,23]. Small particles may be inhaled and penetrated into the lungs causing inflammatory reactions in the respiratory system [24]. Other studies [9] suggest that health effects can occur at PM levels that are at or below allowable international air quality standards. In fact, there is little indication that there is a limit below which dust causing PM pollution does not have adverse health effects, particularly for the most vulnerable like children.

Bad air quality in school buildings can be of critical importance for the comfort, performance, and mainly for the health of the students and staff. The populations potentially at greatest health risk are school children. School buildings are occupied by students at a developing age when sustained exposure to air pollutants could be critical. Children spend at least a third of their time inside school buildings, or approximately seven or more hours a day in school. Furthermore, children are more vulnerable to some environmental pollutants than adults, since they breathe higher volumes of air relative to their body weights while their tissues and organs are developing [25]. The greater breathing rate in children increases risk of PM induced lung damage. Likewise, children suffer from higher exposure to air pollutants than adults because of their physical activity and higher metabolic rate [26]. Children also tend to absorb pollutants more readily than adults and retain them in the body for longer periods of time. Dr. Malcolm Sears [27] of McMaster University asserts that indoor contaminants are the main sources of threat to the respiratory health of children.

The importance of the indoor environment in schools for children's health and educational performance is well recognized. In a recent review, Mendel and Heath [25] concluded that indoor environmental quality can reduce student performance. Other studies [28,29] have concluded that indoor environmental quality determines an overall sense of wellbeing and shapes attitudes of students, teachers, and staff, which in turn affects teaching and academic performance. A recent study by Wargocki and Wyon [30] demonstrated that air quality in classrooms is an important factor in the learning process and improving it should be given as much priority as improving teaching materials and methods. Poor IAQ can affect scholarly performance and attendance according to several studies [31–39]. In fact, asthma-related illness is one of the leading causes of school absenteeism [40]. High levels of CO_2 have been shown to cause a negative influence on pupils' learning ability [41]. Therefore, the failure to avoid indoor air pollution can potentially escalate long and short-term health problems for students and staff, diminish the efficiency of teachers, and worsen the learning environment and general comfort.

Effective ventilation systems are normally used to distribute adequate amounts of outside air to occupants and remove pollutants by diluting accumulated levels of indoor contaminants. Norback et al. [42] found high levels of volatile organic compounds (VOCs) and CO_2 concentrations producing incidences of sick building syndrome (SBS) in six primary schools due to inadequate ventilation.

However, it is not known how effective these systems can be if there are elevated pollution levels outdoors. Air quality measurement for total volatile organic compounds (TVOC) and CO_2 at 185 schools in Sweden were carried out by Gustén and Strindehag [43]. The study revealed that outdoor contamination sources play a major role in affecting the indoor air quality.

In Kuwait, rapid development has seen an increase in air pollution, particularly from industrial sources (mainly the petroleum industry), dense population, and increased motor vehicle usage, posing significant threats to human health and the environment. These sources of pollution release carbon monoxide, sulfur dioxide, particulate matter, nitrogen oxides, hydrocarbons and other air pollutants such as volatile organic compounds (VOCs). One study [44] has recounted that of all developed countries, the ambient air in Kuwait has the highest levels of VOC emission.

In addition, located in a hot climate necessitates intensive and continuous use of air conditioning, and thus, higher demands for energy consumption. The energy to operate such equipment is provided through the combustion of large amounts of fuel, which in turn increases the emission rates of NOx, sulfur dioxide, and solid particulates. Al-Azmi, V. Nassehi and A. R. Khan [45] have shown in their study the increase in emission rates of SO_2 and NOx from power stations in Kuwait.

Due to its desert environment, high particulate levels are also to be expected in Kuwait, which is affected by frequent dust storms. A 2008 study [46] showed the mean annual concentrations for PM10 ranged from 66 to 93 g/m^3 across three sites in Kuwait, which exceeds the World Health Organization (WHO) air quality guidelines for PM10 of 20 g/m^3.

In such an environment, there is a possibility that elevated levels of various outside pollutants will contribute to pollutant levels indoors. For example, VOCs previously measured in Kuwait was found to be greater indoors than outdoors [47].

Although there are studies that have been performed to assess the outdoor air quality in various areas of Kuwait, there is no qualitative information on health complaints and IAQ problems in schools. Therefore, a significant gap exists regarding baseline data for indoor air quality in public school buildings in Kuwait and conducting a study in these types of buildings is warranted. Moreover, education is a crucial component of the child's social development and high-quality school buildings are required for this purpose. Satisfactory IAQ is an important element of a healthy indoor environment, and can aid schools attain their objective of educating children. Accordingly, the objectives of this study are to collect air samples, characterize the concentrations of different indoor air pollutants at selected secondary schools in Kuwait, to compare the measured concentrations with relevant standards and identify schools with air quality problems, and to suggest the basic strategies to reduce the exposure of school children to undesirable pollutants. The results can help environmental decision makers and government policy makers improve IAQ by means of appropriate urban planning and remedial measures resulting in a favorable learning environment with better children performance.

2. Materials and methods

2.1. Overview of target buildings

Of the 132 gender segregated high schools in Kuwait, 46 schools were selected as a sampling size for this study. The number of schools selected represented an appropriate statistical number (or above 30% of the total number of schools). Of those selected, 24 were schools for girls. The schools were selected randomly and were located geographically in all the urban areas of Kuwait (Fig. 1).

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