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Comparison of indoor air quality in schools: Urban vs. Industrial 'oil & gas' zones in Kuwait

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ABSTRACT

This study was conducted to assess indoor air quality during a complete school calendar year and covered all climatic seasons. IAQ parameters were examined to assess pollutant levels in Kuwait schools in multiple settings (classrooms, painting rooms, computer labs, science rooms, teachers' rooms, and roofs). Schools were randomly selected from two zones: zone 1 which is located close to downtown and represents the 'urban sector', and zone 2 which is located further south in close proximity to the oil and gas industrial region and represents the 'industrial sector'. Indoor air investigation included the following parameters: CO_2, SO_2, NO_2, H_2S, formaldehyde, acetaldehyde, TVOC, and nine elemental concentrations of PM_{10}, namely: As, Co, Cr, Fe, Pb, V, Al, Cd, and Hg. Dust from air conditioning filters was also collected and analyzed for both PAHs and PBDEs. *T*-test, one-way ANOVA, Two-way ANOVA and linear regression were tested to identify seasonal, location, and zone variations. On-way ANOVA identified significant seasonal variation for NO_2, H_2S, formaldehyde and acetaldehyde. Factorial ANOVA demonstrated that the schools varied significantly on TVOCs. High concentrations of PAHs and BDE-209 cogener were also present in most schools. Analysis of dust from AC filter units along with measurements of indoor air pollutants can improve our understanding of the common sources of typical pollutants indoor. This study, to our knowledge, presents the first comprehensive analysis of indoor air parameters, including dust analysis from AC filters, in schools in the MENA region 'Middle East and North Africa'.

1. Introduction

Many research has been published in the subject of indoor air quality (IAQ) in schools, particularly in primary, elementary, and middle schools for various reasons such as higher susceptibility of children to environmental pollutants [1,2], higher inhalation rates per body mass [3], and longer time spent in schools [4]. A mega study of over 300 peer-reviewed articles and 87 health education reports from 1982 to 1999 by Daisey [5] reported that the prevalence of respiratory diseases such as asthma and allergies are associated with school health environment, and that, ventilation is inadequate in many classrooms. Vincent [6] stated that air quality inside schools is often worse than outdoor pollution, leading to various health complaints and loss of productivity. Poor IAQ in school buildings has adverse effects on academic performance of students [7–9]. Exposure to indoor air pollutants affects peoples' perceptions even at low concentrations normally found in schools [10].

Studies identified different pollutant parameters that contribute to IAQ problems in samples of schools in various countries; for instance, high PM_{10} and CO_2 levels in Porto, Portugal [11], Hong Kong [12] and Munich, Germany [13]; high mean concentrations of both PM_{10} and $PM_{2.5}$ in Lahore, Pakistan [14]; higher mean indoor CO_2 concentration than the ASHRAE standards-62 [15] of 1000 ppm in Athens, Greece [16,17], and Serbia [18], or the CO_2 value established by Portuguese legislation [19]; high CH_2O concentration emitted by building materials or furnishings in South Korea [20] and France [21]; and high average SO_2 concentrations in French schools [22].

Although several studies have reported that CO_2 concentration in schools often do not meet building standards due to inadequate ventilation [23–26], other researchers reported that complaints on poor IAQ in schools were not only related to low ventilation or

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increased CO_2 levels, but also to other indoor contaminants [4]. Comparison of indoor and outdoor concentration of CO at a public school in Central Athens showed that the mean daily I/O concentration ratios ranged between 0.49 and 0.89; indoor measurements were conducted using a Dasibi 3008 non-dispersive infrared (NDIR) CO analyzer [27]. Wargocki et al. [28] suggested that IAQ could be improved by increasing the fresh air intake and minimizing the emissions by curtailing the sources of volatile organic compounds (VOCs) in a simulated office environment. Indoor pollutant concentrations in schools reflect outdoor concentrations for PM_{10} [29] and for PM (0.3–20 μm) and NO_x regardless of building airtightness [30].

The measured indoor concentrations of some pollutants were reported to be higher than the outdoor concentrations in buildings which are similar to school settings. For instance, Lai et al. [31] reported higher $PM_{2.5}$ analyzed for 37 metals, total volatile organic compounds (TVOC) including 30 organic compounds, NO_2 and CO in Oxford City, UK. Zuraimi et al. [32] compared the IAQ in European and Singaporean office buildings. They reported high concentration of 2-methylpentane, n-hexane and isoprene in European buildings as compared to Singaporean buildings, while n-tetradecane, 2-ethyl-hexanol, benzene, toluene, m/p-xylene, benzaldehyde and nephthelene are high in Singaporean buildings due to low fresh air intake.

Despite the large number of published research investigating IAQ in schools, only one study regarding IAQ in Kuwaiti schools has been undertaken [33]. Few other studies investigated practices leading to indoor air pollution and the prevalence of symptoms in the homes of Kuwaiti students [34,35]. Other researchers investigated ambient air quality in the vicinity of Kuwaiti schools [36]; while others extensively studied IAQ in Kuwaiti homes [37–41]. This article is based on the detailed research project that has been conducted in the Kuwait Institute for Scientific Research (KISR) and completed in 2012 [42]. This article presents a procedure to carry out a comprehensive IAQ investigation in schools using passive samplers, portable CO_2 monitors, sequential particulate sampling, and dust sampling from air conditioning filters.

2. Materials and methods

2.1. School selection and sampling sites

Kuwait is considered a very small country (17,820 km^2 in size). At its most distant points, it is about 200 km north to south, and 170 km east to west. Populated land is only 7% of the country running along the coastline. School selection was performed using a clustered stratified sampling design. Since Kuwait does not have rural areas, it was decided that stratification is classified as urban vs. industrial cluster. Random selection of schools within each cluster/zone was chosen. Fig. 1 shows location maps for the two selected school zones in the study. Indoor measurements were conducted in seven schools randomly selected from two different zones in Kuwait; zone 1 is located close to downtown and represents the urban sector, and zone 2 is located further south in close proximity to the oil and gas industrial region and represents the industrial sector. A total sample of seven schools were randomly selected from both zones; two elementary schools (one for boys 'Al-Ahmadiya, abbreviated as AHA′, one for girls 'Al-Mansouriya, abbreviated as MAN′) and one intermediate school (girls 'Al-Dasma, abbreviated as DAS) from zone 1; and three elementary (two for girls 'Behat Al-Badiya BBD and Al-Shuaiba SUB′, one for boys 'Benaider BDR′) and one intermediate (boys 'Abdullah Bin Zubair ABZ′) from zone 2. Schools from zone 2 are newly built; zone 1 urban area schools are much older, with one school dating back to 1960; however, all zone 1 schools were recently renovated. All schools are public and consist of two floors, comprised of children aged 6–10 years old and 11–15 years old for elementary and intermediate schools, respectively. All schools use split type air conditioning units in all classrooms, except BBD in zone 2 which was recently built (2004), and it is the only school with full mechanical central air conditioning system. Split type air systems, by default, do not allow for outside ventilation. Table 1 presents the main characteristics of the schools selected.

Within each school, different sites were investigated for IAQ depending on presence or suspicion of indoor sources of pollution [43]. The sites investigated for IAQ were the following: classrooms, science preparation labs, computer labs, painting rooms, teachers' rooms, decoration rooms, and roofs. Investigation period was carried out during one complete school calendar year (2011/2012) covering all 4 climatic seasons of Kuwait, i.e., fall (October, November), winter (December, January, February), spring (March, April, May) and summer (June, July, August, September).

2.2. IAQ sampling and analysis

Sampling included carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), hydrogen sulfide (H_2S), Aldehydes (formaldehyde CH_2O and acetaldehyde CH_3CHO), volatile organic compounds (VOCs), and particulate matter (PM_{10}). Also, elemental concentrations of PM_{10}, namely arsenic (As), cobalt (Co), chromium (Cr), iron (Fe), lead (Pb), vanadium (V), aluminum (Al), cadmium (Cd), and mercury (Hg). Polycyclic aromatic hydrocarbons (PAHs) and polybrominated diphenyl ethers (PBDEs) were analyzed from sampling of dusts from air conditioning (AC) units' ventilation filters.

Monitoring was conducted in occupied classrooms during regular daily school hours (7:30 a.m.–1:45 p.m.) and under representative conditions of activities and occupancy. All doors were closed during the sampling period and opened only before the beginning of classes and after closing sessions; each class session lasted approximately 50 min. Classrooms had insulated glass windows with rubber seals. Sampling equipments were positioned in safe and tampering-free locations. The measuring instruments were placed on a flat surface with a height of 1–1.5 m to simulate school children's' breathing zone. Instruments were located roughly 1 m away from walls, doors or air conditioning units. All air conditioning systems (split-type units) were in operation in all schools during air sampling.

The CO_2 concentration levels were measured using a portable CO_2 meter (range 0–5000 ppm), manufactured by Extech instruments corporation (model CO250) with non-dispersive infrared sensor. The instrument is also capable of measuring air temperature, dew point, wet bulb temperature, and humidity. The CO_2 monitoring device was connected to a computer, which was placed in the selected site in each school and taking continuous readings every 30 min to 1 h. Three locations were randomly selected (classrooms, computer labs, teacher rooms) based on short-term CO_2 monitoring reflecting physical activity level, type of room, and air exchange rate. CO_2 monitoring was recorded, covering an entire typical local school week (Sunday to Thursday) during occupancy, and also during the weekend (Friday and Saturday). Sampling instrument (portable CO_2 meter) was located at 1.5 m above floor level.

Other indoor air parameters such as temperature and relative humidity (RH) were recorded simultaneously. Across all schools, average temperature was recorded to be 21.3 °C, within a range of 20.1–23.5 °C in all classrooms. More than 95% of classrooms had relative humidity between 30% and 50%, with an average RH of 41.2% across all classrooms. Indoor airflow speed was not calculated; however, average surrounding air speed was recorded from