



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



Ali Al-Hemoud^{a,*}, Layla Al-Awadi^a, Mufreh Al-Rashidi^a, Khan Abdul Rahman^a,
Ahmed Al-Khayat^b, Weam Behbehani^b

^a Crisis Decision Support Program, Environment and Life Sciences Research Center, Kuwait

^b Techno-Economics Division, Kuwait Institute for Scientific Research, P. O. Box 24885 13109 Safat, Kuwait

ARTICLE INFO

Article history:

Received 10 April 2017

Received in revised form

21 May 2017

Accepted 1 June 2017

Available online 3 June 2017

Keywords:

Indoor air quality

Schools

VOCs

PM₁₀

Polycyclic aromatic hydrocarbons (PAHs)

Polybrominated diphenyl ethers (PBDEs)

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: CO₂, SO₂, NO₂, H₂S, formaldehyde, acetaldehyde, TVOC, and nine elemental concentrations of PM₁₀, 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 NO₂, H₂S, 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'.

© 2017 Elsevier Ltd. All rights reserved.

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 PM₁₀ and CO₂ levels in Porto, Portugal [11], Hong Kong [12] and Munich, Germany [13]; high mean concentrations of both PM₁₀ and PM_{2.5} in Lahore, Pakistan [14]; higher mean indoor CO₂ concentration than the ASHRAE standards-62 [15] of 1000 ppm in Athens, Greece [16,17], and Serbia [18], or the CO₂ value established by Portuguese legislation [19]; high CH₂O concentration emitted by building materials or furnishings in South Korea [20] and France [21]; and high average SO₂ concentrations in French schools [22].

Although several studies have reported that CO₂ 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

* Corresponding author.

E-mail address: ahomood@kisir.edu.kw (A. Al-Hemoud).

increased CO₂ 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 PM₁₀ [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, NO₂ 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 naphthalene 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 CO₂ 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 km² 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 (CO₂), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), hydrogen sulfide (H₂S), Aldehydes (formaldehyde CH₂O and acetaldehyde CH₃CHO), volatile organic compounds (VOCs), and particulate matter (PM₁₀). Also, elemental concentrations of PM₁₀, 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 CO₂ concentration levels were measured using a portable CO₂ 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 CO₂ 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 CO₂ monitoring reflecting physical activity level, type of room, and air exchange rate. CO₂ 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 CO₂ 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

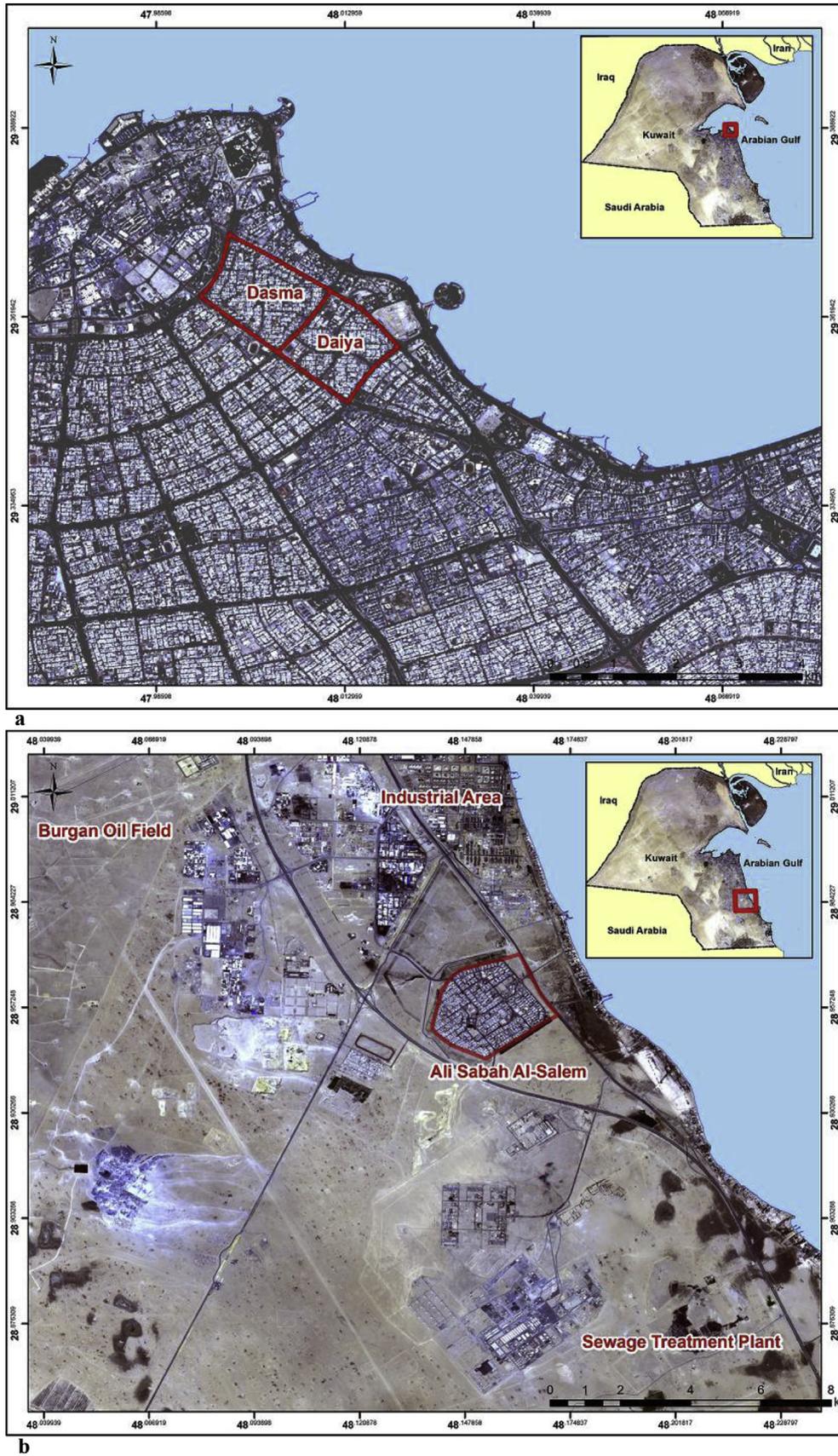


Fig. 1. a. Map showing zone 1 'urban sector' from which three schools were randomly selected. b. Map showing zone 2 'industrial sector' from which four schools were randomly selected.

Table 1
Main characteristics obtained from the selected schools.

	School name	Gender	Total no. of students	Max. students/class	Year of establishment
Zone 1	MAN	Girls	414	22	1979/2010 ^a
	AHM	Boys	254	27	1973/2010 ^a
	DAS	Girls	584	25	1960//2009 ^a
Zone 2	BBD	Girls	618	25	2004
	BDR	Boys	753	29	2002
	ABZ	Boys	1200	35	2002
	SUB	Girls	781	27	2002

^a Year of complete renovation.

meteorological stations as 3.5 m/s, 3.9 m/s, 4.3 m/s and 5.3 m/s for fall, winter, spring and summer seasons, respectively. Average atmospheric pressure (ha) from nearby stations was recorded as 1008.8, 1012.8, 1005.7 and 995.4 for fall, winter, spring and summer seasons, respectively.

A total of 290 passive samplers were used to quantify SO₂, NO₂, H₂S, formaldehyde, and acetaldehyde in indoor air during four seasons/waves throughout one complete school year to represent different climatic conditions, i.e., October (fall), February (winter), May (spring), and August (summer). Diffusion samplers were used simultaneously as recommended by the manufacturer (IVL Swedish Environmental Research Institute). The pollutant is transported to the sorbent by molecular diffusion (or permeation). The average sampling rate (sorbed amount per unit time divided by the ambient concentration, e.g., cm³ min⁻¹) is a temperature-dependent constant for a given pollutant and sampler. The sampler consists of a tube which has a cap on one end containing a filter, impregnated with a solution, specific to absorb the pollutant to be measured. The air with contaminants is transported into the tube through the open end by molecular diffusion. To protect the sampler from the wind artifact that creates a turbulent diffusion inside the sampler, the inlet is protected with a very porous membrane. The membrane is protected from mechanical damage by a stainless steel screen. The samples were collected after a particular period of time based on the type of compound and concentrations, for instance one school week sampling for formaldehyde. The limits of detection were 0.2 µg/m³ and 0.1 µg/m³ for SO₂ and NO₂, respectively.

VOC concentrations (>900 samples) in schools were measured using pre-evacuated silicon-coated 6-L capacity stainless steel canister during occupancy and later analyzed using Entech cryogenic Agilent GC FID/ECD (Compendium Method TO-14A, EPA 1999) [44]. The GC/FID was commissioned with a pre-concentrator and auto sampler in a specially refurbished laboratory at KISR with proper quality control and quality assurance [45]. VOCs from a sample volume of about 800 cm³ were pre-concentrated in a liquid nitrogen cooled sample loop (200 mm long, 2 mm diameter) filled with inert glass beads with diameter of 0.25 mm. The flow of sampled air was kept at 80 cm³ min⁻¹ resulting in 10 min sampling interval. When sampling was complete, the sample loop was heated up to 120 °C and the hydrocarbons were injected on the capillary column (DB-1; 120 m × 0.32 mm ID, film thickness: 3 µm). After injection, the column was kept isothermal at -60 °C for 5 min and then heated up to 200 °C with a rate of 5 °C min⁻¹. Subsequently the column temperature was kept at 200 °C for 15 min. After cooling down the GC oven, a new analysis is started. The complete analysis usually takes about 90 min. The sensitivity of the GC-system was checked periodically by calculating the experimentally derived mass response factor (MRF) of a 120 components calibration non-methane hydrocarbon, NMHC gas mixture. The MRF_i of an individual compound is defined as: $MRF_i = MF_i / (\mu_{HC_i} \cdot MW_{HC_i})$ where, FE_i is the peak area, µ_{HC_i} is the known mixing ratio in ppb of HC_i in the standard and MW_{HC_i} is the molecular

weight (g mol⁻¹) of HC_i. Average MRF was calculated from a regression analysis of the measured peak areas against µ_{HC_i} · MW_{HC_i} and used for the calculation of the NMHC concentrations. The average MRF remained constant within 5% during the whole canister-sampling period and has shown no significant dependence on the hydrocarbon, except for ethyne (acetylene). Individual peaks in the chromatogram were identified via injection of the pure species and the identification was confirmed using the component gas mixture. Individual mixing ratios µ_{HC} of HC_i were calculated from the respective peak areas FE_{HC_i}. Poorest detection limit was achieved in case of ethane (DL_{Ethene} = 70 ppt), which co-eluted with CO₂. The mean detection limits for other hydrocarbons varied between 10 ppt (C₃ compounds) and 3 ppt for hydrocarbons > C₈. It has to be noted that due to co-elution only sums can be listed in case of 1-butene/2-butene and m-xylene/p-xylene.

2.3. Dust sampling

Sequential particulate sampler devices for collecting PM₁₀ in outdoor environments were stationed on randomly selected schools, one from each zone. Sequential sampler device was placed in the playing yard of AHM school from zone 1 and on the roof of BBD school from zone 2. The device was operated for 24 h and collected PM₁₀ dust samples based on its selective operation on glass fiber filters for nine trace metals, mainly arsenic (As), cobalt (Co), chromium (Cr), iron (Fe), lead (Pb), vanadium (V), aluminum (Al), cadmium (Cd), and mercury (Hg). Determination of trace metals used total decomposition methods procedure [46]. Dust from recirculation filters of HVAC systems was collected from the AC units (both central and split) from various rooms at all schools in both zones in May during pre-summer routine scheduled maintenance. Central AC systems have 10% built-in provision for fresh air intake, which is often closed for better cooling and energy conservation. AC split units do not allow for outside ventilation. Dust analysis included trace metals, PAHs and PBDE. Dust sample analysis for PAHs was conducted using gas chromatography-mass spectrometry (Hewlett-Packard 6890 GC interfaced with a Hewlett-Packard 5973 mass spectrometer) using MOOPAM procedure [46] and EPA methods 610, 8272 [47,48]. Dust samples were prepared by extraction of target contaminants from the bulk matrix, followed by isolation of the contaminants from other organic molecules, and purification of the extract, prior to instrumental analysis. Different materials were used in sample preparation; the first quantity contained PAH solution kit, Z-013-17 (mix of 16 priority PAHs; AccuStandard) and 200 ppm in MeOH:CH₂Cl₂, and the second quantity for deuterated PAHs includes naphthalene-d₈, acenaphthene-d₁₀, phenanthrene-d₁₀, chrysene-d₁₂, and perylene-d₁₂ (Z-014J-PAK); 6 compounds, 200 ppm. A mixture of 50% hexane in dichloromethane was used for extraction of PAH from dust and sediment after spiking deuterated PAHs with Soxhlet apparatus. Then, clean sample was extracted by silica gel to remove impurities. Sample extracts (2 µl) were injected into a Hewlett-

Packard 6890 GC interfaced with a Hewlett-Packard 5973 mass spectrometer. Injections were made in splitless mode, and PAHs were separated on a 30-m DB-5 (5% diphenyl/dimethylpolysiloxane) capillary column (250 μm i. d. X 0.25- μm film thickness). The oven temperature program was set to 100 °C for 1 min, 3 °C/min to 200 °C, held for 3 min, 2 °C/min to 290 °C, held for 5 min. The inlet and interface temperatures were set to 250 °C and 300 °C, respectively. Quantification ions for PAHs were then monitored for each compound. Quantification of individual PAHs was based on external calibration standards containing known concentrations of 16 priority PAHs. The term ΣPAH refers to the sum of 16 priority PAHs. As quality assurance, deuterated PAHs spiked into the samples should show acceptable recoveries ranging from 72 to 125%. Detection limits for individual PAHs in samples were calculated. A procedural blank was included in each analysis. Matrix spikes were performed with each batch of 20 samples. Instruments should be calibrated prior to running the samples; calibration was performed by injection standards at different concentrations with calibration coefficients >0.99.

Determination of PBDEs followed the standard analytical method (EO-5099) from Cambridge Isotope Lab (CIL). A total of 14 PBDE (BDEs 17, 28, 71, 47, 66, 100, 99, 85, 154, 153, 138, 183, 190, and 209) congeners were detected and quantified. The $\Sigma_{14}\text{PBDE}$ refers to the sum of all the congeners measured in the study [42]. Dust was screened through a 20 μm gauge sieve into a solvent-rinsed aluminum foil to remove debris and other large particles and immediately transferred to a clean, solvent-rinsed amber glass bottle and kept at -20 °C for analysis. The samples were extracted in triplicate in a Soxhlet apparatus using 150-ml (1:1 v/v) mixture of dichloromethane (DCM) and hexane. Prior to extraction, the samples were spiked with Mirex as internal standard. The extracts were reduced in volume on a Turbovap concentration workstation, solvent was exchanged to hexane, and interfering compounds were removed by column chromatography using 5-g silica and 2-g alumina (and filled top 5 mm of the column with anhydrous Na_2SO_4 to prevent the column contacting with air) and eluting the compounds of interest with 60-ml (1:1) mixture of DCM and hexane. The sample extracts were analyzed with an Agilent 6890N gas chromatograph using splitless injection on a 15-m DB 5-MS column (0.25-mm id, 0.25 μm film thickness) with oven program at 80 °C for 2 min then ramped at 25 °C min^{-1} to 220 °C, 5 °C min^{-1} to 315 °C held for 10 min. This is coupled to an Agilent 5973 inert mass selective detector, operated in NCI mode (using selected ion monitoring), with methane as reagent gas. Identification and quantification were carried out against four calibration standards. A total of 9 PBDE congeners were regularly detected in samples and quantified. For QC/QA an analytical blank was processed for every 5 samples. Blanks consisted of 5 g of anhydrous Na_2SO_4 (previously baked at 450 °C), spiked with surrogates and taken through the entire analytical process for actual samples. A peak was positively identified if it was within ± 0.05 min of the retention time in the calibration standard, and quantified only if the ratio of the target ion to its qualifier ion were within $\pm 20\%$ of the standard value. The PBDEs present in the appropriate blank were subtracted from those in the sample extracts. The method detection limits (MDLs) were calculated as the mean blank $\pm 3\sigma$.

2.4. Statistical analysis

Multiple statistical analysis techniques were used to compare IAQ pollutant concentrations and test for significant differences between zones, seasons and locations within schools. *T*-test was conducted to compare differences between the two zones (urban vs. industrial) for SO_2 , NO_2 , H_2S , formaldehyde, acetaldehyde, PM_{10} , PAH and PBDEs. One-way ANOVA was used to make comparisons

by seasons and locations for SO_2 , NO_2 , H_2S , formaldehyde and acetaldehyde. Two-way ANOVA was conducted to test for significant interaction for TVOCs; one two-factor ANOVA employed a 2×3 factorial design with zones 1 and 2 as one variable and three locations (classrooms, painting rooms, and science rooms) as the second variable, while the second two-factor ANOVA (3×7 design) tested if differences in TVOCs existed between the three selected locations and the seven schools. Simple linear regression model was tested to produce an equation describing the line of best fit between TVOC and seasons. Null hypothesis was tested for a *P*-value of 0.01 or 0.05.

3. Results

3.1. CO_2 monitoring

Fig. 2 shows the variation of indoor CO_2 concentrations on a typical week in three locations (classroom, computer lab, teacher room) in selected schools from both zones. It was apparent that average CO_2 levels in DAS school (zone 1) exceeded 1000 ppm [15] starting from the beginning of the school week (Sunday) to the end of the school week (Thursday) in both the classroom and computer room; however, average CO_2 levels dropped sharply during the weekend (Friday and Saturday). Average CO_2 levels in the teachers' room in all schools showed lower values (all below 700 ppm). The higher occupancy of students in the classroom and computer room, and closing of windows and doors during class hours caused the high CO_2 levels. It is worth noting that BBD is the most modern school (built in 2004), and it is the only school with full mechanical central air conditioning system; thus, it is associated with lower CO_2 levels.

3.2. Passive sampling concentrations (SO_2 , NO_2 , H_2S , formaldehyde and acetaldehyde)

Table 2 presents the *t*-test summary table for average pollutant concentrations from passive sampling. Results revealed that there were no significant differences between zone 1 and zone 2 for three pollutant concentrations; SO_2 ($p = 0.967$), H_2S ($p = 0.210$) and acetaldehyde ($p = 0.847$). Most of the SO_2 concentrations were low in both indoor and outdoor air (roof) at all locations in all schools in both zones; values were below 20 $\mu\text{g}/\text{m}^3$ for 24-h mean suggested by the World Health Organization [49]. I/O ratio exceeded unity suggesting outdoor sources, mainly from burning high sulfur crude oil in zone 2 and from the presence of heavy traffic and gasoline dispensing facilities nearby in zone 1. All H_2S concentrations appeared to be insignificant when compared to WHO lowest observed adverse effect level (LOAEL) of 150 mg/m^3 'equivalent to 10 ppm, 100 ppb'. Acetaldehyde concentrations were relatively low across all schools in both zones. Significant differences existed between zones for NO_2 concentrations ($p = 0.001$); average concentrations were slightly higher for zone 1 schools than zone 2 schools. Highest concentration was detected in the science room of MAN school (24.33 ppb) due to the use of nitric acid (HNO_3) and extensive use of Bunsen burners in laboratories. Weekly average concentrations for NO_2 exceeded the WHO guideline [50] for long-term exposure (40 $\mu\text{g}/\text{m}^3$ '20 ppb' for one-year average) in some classrooms in MAN, AHM and BBD schools. Formaldehyde concentrations were significantly different at the 0.05 level ($p = 0.22$) for both zones. Almost all indoor formaldehyde concentrations in both zones exceeded outdoor levels (roof), suggesting that indoor sources are the main origin. Zone 1 schools had higher average formaldehyde concentrations than zone 2 schools. Most painting and science rooms in all schools in both zones exceeded the 30-min average concentration of 100 $\mu\text{g}/\text{m}^3$ '81 ppb' for formaldehyde [50].

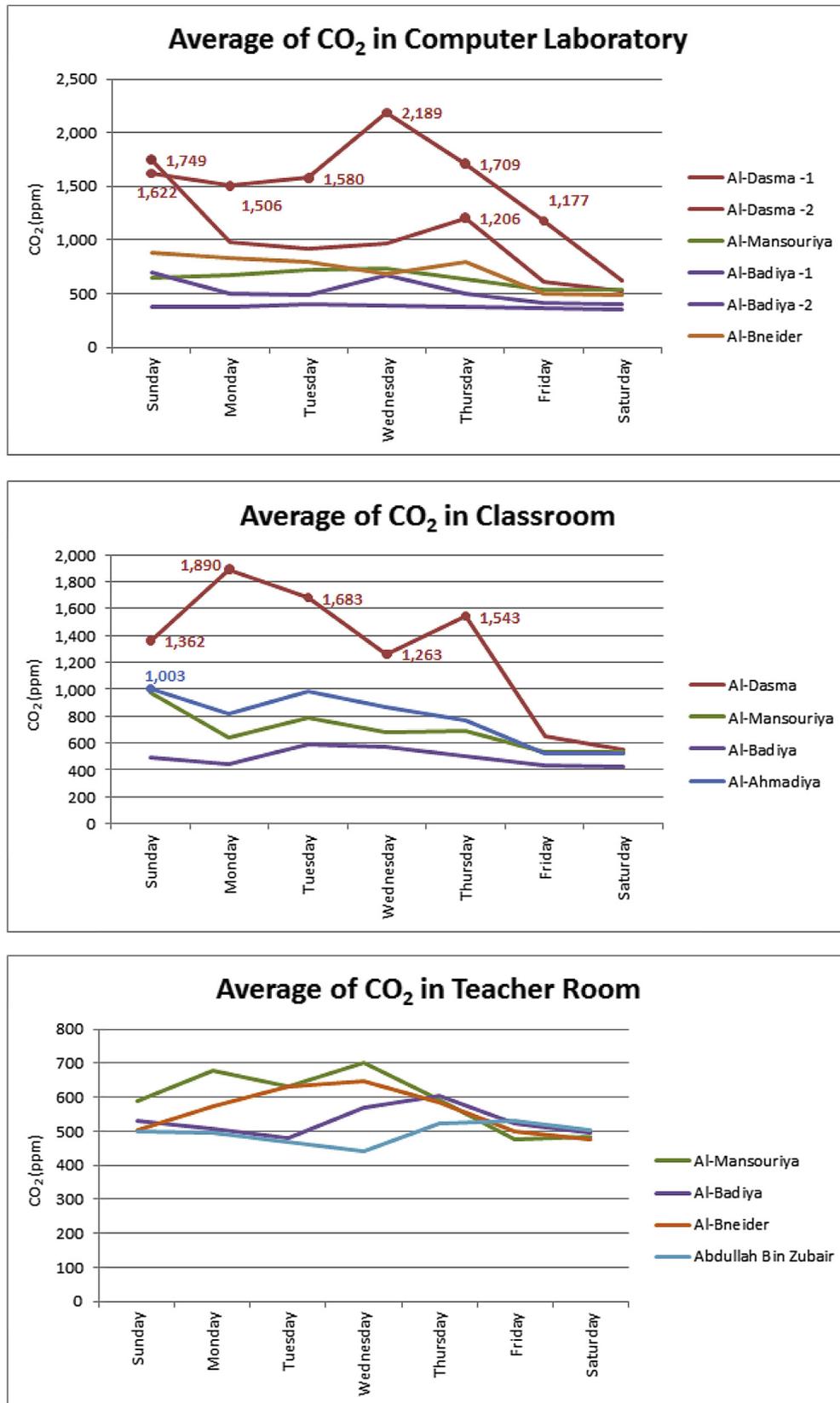


Fig. 2. Daily average CO₂ levels in selected locations in schools.

Seasonal variations existed significantly for NO₂ (at the 0.05 level, $p = 0.03$) and for H₂S, formaldehyde and acetaldehyde at the 0.01

level ($p = 0.00$). Higher formaldehyde concentrations were apparent in August (summer season) because of closed rooms, no

Table 2a

T-Test summary table for average pollutant concentrations (in ppb) - comparison by zones.

Pollutant	Zone 1	Zone 2	T-test	Sig.
SO ₂	2.71	2.75	-0.042	0.967
NO ₂	16.29	13.10	3.565	0.001*
H ₂ S	4.53	3.87	1.267	0.210
Formaldehyde	61.15	39.54	2.325	0.022**
Acetaldehyde	2.15	2.09	0.193	0.847

*p-value ≤ 0.01, **p-value ≤ 0.05.

Table 2b

One-way ANOVA summary table for average pollutant concentrations (in ppb) - comparison by seasons.

Pollutant	Fall	Winter	Spring	Summer	F	Sig.
SO ₂	2.66	1.58	2.28	4.22	2.055	0.111
NO ₂	16.05	15.28	13.67	12.63	3.123	0.030*
H ₂ S	4.23	2.46	2.90	6.32	36.52	0.000*
Formaldehyde	35.36	38.58	35.29	75.86	5.87	0.000*
Acetaldehyde	2.85	2.83	—	0.963	26.96	0.000*

*p-value ≤ 0.01, **p-value ≤ 0.05.

Table 2c

One-way ANOVA summary table for average pollutant concentrations (in ppb) - comparison by locations within schools.

Pollutant	Classroom	Science room	Painting room	Roof	F	Sig.
SO ₂	0.823	0.809	0.431	8.82	122.5	0.000*
NO ₂	15.81	14.44	12.19	12.63	3.016	0.034**
H ₂ S	4.99	4.33	5.42	3.26	3.593	0.019**
Formaldehyde	58.58	44.79	84.7	1.23	27.246	0.000*
Acetaldehyde	2.69	2.55	2.17	1.09	5.829	0.0018

*p-value ≤ 0.01, **p-value ≤ 0.05.

air circulation and build-up of higher pollutants. Locations within schools showed significant differences for all pollutant concentrations. Higher concentrations were recorded in classrooms for NO₂ and acetaldehyde, while painting rooms had higher concentrations for formaldehyde and H₂S possibly caused by off-gassing from urea formaldehyde foam insulation, plywood, carpeting, fabrics, glues, adhesives, and window cleaners.

3.3. VOC concentrations (aliphatic, aromatic, halogenated, oxygenated)

Table 3 shows monthly average total VOC concentrations in selected locations in all schools from both zones. There were no significant differences in seasonal variations for monthly average total VOC concentrations ($p = 0.229$). Overall, lowest TVOC concentrations were noticed during winter in all classrooms and science rooms. The results of the two-way ANOVA tests (Table 4) disclosed that there was a significant difference between the two zones, with zone 1 having higher monthly average TVOC concentration (649.43 ppb) than zone 2 (401.90 ppb) ($F = 8.022$, $df = 1$, $p < 0.01$, $Sig = 0.006$). There was no significant difference among the three locations selected (classrooms, painting rooms, and science rooms) ($F = 1.767$, $df = 2$, $Sig = 0.176$) on TVOC, nor was there a significant interaction between zones and locations ($F = 1.311$, $df = 2$, $Sig = 0.274$). Although the painting rooms in all schools had higher monthly average TVOC concentrations (605.31 ppb) than the science rooms and classrooms, 523.1 ppb and 415.38 ppb, respectively, Tukey test for multiple comparisons showed no significant difference among the three locations ($Sig = 0.147$). Simple factorial ANOVA test showed that the seven schools varied significantly on TVOC ($F = 3.199$, $df = 6$, $p < 0.01$, $Sig = 0.007$); however,

no significant interaction was revealed between locations and schools ($F = 1.086$, $df = 11$, $Sig = 0.381$). Two similar subsets were identified for TVOC in schools using the Tukey test for multiple comparisons of means. The first subset identified all schools with similar TVOC, except DAS with higher average TVOC (888.76 ppb) than the remaining six schools ($Sig = 0.157$), and the second subset identified similarities between BBD and MAN (lower TVOC concentrations; 241.78 ppb and 396.08 ppb, respectively) in relation to the remaining five schools ($Sig = 0.56$). It is worthy to note that the highest monthly VOC concentrations in all schools fell within the halogenated and oxygenated groups; over 72% of all VOCs recorded were methanol, ethanol, and chlorodifluoromethane (Freon or refrigerant CFC 22). In almost all classrooms, ethanol and CFC 22 were more abundant in May; ethanol (highest average concentration was 1348.56 ppb in DAS), main source was related to solvents, adhesives, and clipboards; while CFC 22 (highest average concentration was 305.65 ppb in SUB), main source was associated with AC split unit refrigerant leaks. Highest TVOC concentrations in the painting rooms were noticed in DAS (2489.60 ppb) and AHM (1244.28 ppb) schools in May; highest recorded compounds were acetone (78%, 1220.5 ppb) and vinyl chloride (78%, 1168.14 ppb),

and tetrachloromethane (542.81 ppb) and toluene (358.40 ppb); in DAS and AHM schools, respectively. Highest TVOC concentrations in the science preparation rooms were noticed in AHM (2917.96 ppb) and DAS (2533.79 ppb) schools with vinyl chloride (average concentration was 1986 ppb), being the most abundant in both schools. These findings do not correspond with Al-Hubail and Al-Temeemi [33] who identified only one positive reading of VOC in only one classroom out of 46 randomly selected schools. Simple linear regression was tested to determine if monthly average total VOC concentrations changed linearly by seasons. From Table 5, the regression coefficient is insignificant ($p = 0.699$) and the adjusted r^2 is negligible indicating poor linear relationship between average total VOCs across seasons ($r^2 = 0.001$).

3.4. PM₁₀ sequential sampling

The results (Table 6) showed that most elemental concentrations in PM₁₀ were low and often below the detection limit, except for Fe, V, Cr, and Co. Negligible values of As, Pb, Al, Cd, and Hg were exempted from the analysis, since they appeared to be insignificant. The highest elemental concentration among all trace metals was for Fe in both zones, AHM school (zone 1), mean was 4.8 $\mu\text{g}/\text{m}^3$ (max 5.84); and BBD School (zone 2), mean was 3.66 $\mu\text{g}/\text{m}^3$ (max 9.92). Fe levels were relatively high due to excessive use of Fe and Fe alloys in fencing, doors, windows, tanks, pipes, and abrasion activities, with corroded iron in local buildings.

3.5. Dust from HVAC system

Elemental concentrations of PM₁₀, total PAH, and total PBDE from AC filters are shown in Table 7. Cd and Hg concentrations were

Table 3
Seasonal monthly average total VOCs (in ppb) and one-way ANOVA tables.

	Month/Year	Zone 1			Zone 2			
		DAS	MAN	AHM	SUB	BDR	BBD	ABZ
Classroom	Fall	682.06	293.69	234.55	529.20	221.69	177.87	–
	Winter	292.08	762.80	230.80	330.38	339.39	235.17	–
	Spring	1032.68	451.13	396.82	747.67	184.43	254.84	–
	Summer	344.91	328.16	245.14	545.65	716.28	234.66	–
Painting Room	Fall	604.86	951.95	365.37	374.15	325.42	–	448.04
	Winter	661.16	412.14	430.93	368.31	746.50	–	795.91
	Spring	1725.61	289.09	841.90	302.99	536.61	453.83	453.29
	Summer	1012.88	434.55	757.42	604.12	564.25	–	177.32
Science Room	Fall	621.64	474.70	1931.65	278.53	181.07	128.72	519.58
	Winter	673.44	214.13	248.48	375.62	282.78	264.25	441.52
	Spring	1481.77	268.10	1633.45	405.08	383.88	165.14	437.06
	Summer	997.70	232.40	336.40	428.42	524.37	309.24	454.49
One-way ANOVA summary table								
	Fall	Winter	Spring	Summer	F	Sig.		
TVOC	491.82	41768	638.28	486.75	1.462	0.229		

*p-value ≤ 0.01, **p-value ≤ 0.05.

Table 4
Two-way ANOVA summary table for monthly average total VOCs.

Source	df	Mean square	F	Sig.
Zone vs. location				
Zone	1	1607942.516	8.022	0.006*
Location	2	354165.267	1.767	0.176
Zone × Location	2	262736.765	1.311	0.274
Error	106	200445.388		
Total	112			
School vs. location				
School	6	598486.408	3.199	0.007
Location	2	232912.972	1.245	0.293
School × Location	11	203181.577	1.086	0.381
Error	92	187063.177		
Total	112			

*p-value ≤ 0.01, **p-value ≤ 0.05.

Table 5
Regression summary table for monthly average total VOCs – by seasons.

Source	df	Mean square	F	Sig.
Regression	1	33002.67	0.150	0.699
Residual	110	219451.31		
Total	112			

r² = 0.001.**Table 6**
Elemental concentrations in PM₁₀ (in µg/m³) from sequential sampling in two selected schools (one from each zone).

	AHM (Zone 1)			BBD (Zone 2)		
	Mean	SD	Max	Mean	SD	Max
Fe	4.80	1.60	5.84	3.66	2.31	9.92
V	0.08	0.02	0.10	0.03	0.03	0.19
Cr	0.15	0.02	0.17	0.005	0.003	0.08
Co	0.01	0.01	0.02	0.0004	0.003	0.02

below the detection limits in all of the samples. Highest elemental average concentrations were detected for Al and Fe in the computer room at BBD school at 50833 µg/g and 71866 µg/g, respectively. These high values were due to contamination of the samples with

Table 7
Dust concentrations from HVAC filters - elemental concentrations of PM₁₀ (in µg/g), total PAH (in ng/g), and total PBDE (in ng/g).

	Zone 1			Zone 2			
	MAN	AHM	DAS	SUB	BDR	BBD	ABZ
As	13.74	5.30	12.71	4.35	–	3.93	7.91
Cd	–	–	–	–	–	–	–
Co	14.35	13.45	13.52	16.25	15.52	4.93	17.23
Hg	–	–	–	–	–	–	–
Cr	80.10	79.30	80.90	80.50	75.60	74.10	80.50
V	65.30	51.10	63.90	74.30	74.50	67.30	72.30
Pb	43.10	50.00	40.30	20.50	74.30	19.10	23.30
Al	34,156	35,332	31,243	35,531	21,341	50,833	25,333
Fe	23,212	25,231	19,233	23,411	34,311	71,866	32,311
Total PAH	1667.0	1013.5	1542.9	618.4	1153.0	654.5	1324.7
Total PBDE	518.3	155.3	645.4	230.3	400.14	31.7	387.3

corroded products containing Al and Fe regularly used in filter frames. Average total PAHs were 50% higher in zone 1 relative to zone 2 schools. The highest mean concentration of total PAHs was 1667 ± 682 ng/g at MAN school, where maximum concentration was reported in the educational technical room (3108.5 ng/g), mainly benzo (b&k)flouranthene and benzo(a)pyrene. DAS and ABZ schools also reported high PAHs; average concentrations were 1542.9 ± 500.2 ng/g and 1324.7 ± 620.9 ng/g, respectively, where higher values were reported in the painting room (2477.8 ng/g) and classroom (2712.6 ng/g) respectively, mainly phenanthrene. Results revealed 67% higher concentrations of PBDEs in zone 1 schools in comparison to zone 2 schools. The highest average concentration of total PBDEs was recorded in DAS school (645.5 ng/g) with the computer laboratory, recorded to be the highest concentration (1067.1 ng/g), and the lowest concentration was recorded in the secretary's room (280 ng/g). The PBDEs in dust samples were dominated by BDE-209 cogener 209 in all schools in both zones. High reported Deca-BDE formulation of BDE-209 in computer laboratories may be related to the intensive use of wire insulations, electronic equipment (e.g. computers, printers, scanners) and other electrical enclosures and gadgets used. Table 8 shows that significant differences between zones were detected only for vanadium (V) with higher elemental concentrations in zone 2 (72.10 µg/g) relative to zone 1 (60.10 µg/g) at the 0.05 level (p = 0.037).

Table 8
T-Test summary table for PM₁₀ (in µg/g), total PAH (in ng/g) and total PBDE (in ng/g) from HVAC filters.

Pollutant	Zone 1	Zone 2	T-test	Sig.
As	10.58	5.39	1.762	0.153
Cd	–	–	–	–
Co	13.77	13.48	0.085	0.935
Hg	–	–	–	–
Cr	80.10	77.67	1.212	0.280
V	60.10	72.10	–2.811	0.037**
Pb	44.46	34.30	0.636	0.553
Al	32700	3326	–0.057	0.958
Fe	22560	40475	–1.402	0.220
Total PAH	1407	938	1.749	0.141
Total PBDE	440	262	1.111	0.317

*p-value ≤ 0.01, **p-value ≤ 0.05.

4. Discussion

The most critical pollutant indoor in all schools was formaldehyde which exceeded outdoor levels, suggesting that indoor sources were the most important contributors to the indoor levels. Formaldehyde concentrations were above the suggested WHO guidelines [50] of 100 µg/m³ '81 ppb' in all schools' locations; that is classrooms, painting rooms, science rooms, teachers' rooms, and decorating rooms; Al-Hubail et al. [33] identified only a single reading above the allowable limit out of 230 total readings in 46 schools in Kuwait. The highest concentration was recorded in the painting room in MAN school during summer (138.6 ppb), when doors are usually closed and high temperature could have intensified the pollutant concentration. It is surprising to note that during the summer vacation, painting rooms were left with all chemicals piled on the tables with few chemical lids left open, resulting in this build-up of high concentrations of pollutants. Formaldehyde concentrations measured in classrooms were higher than those reported in a recent study in Portuguese schools [11]. Off-gassing from paints, glues, and adhesives could have contributed to the high concentration levels [51]. It is also worth noting that smoking constitutes a major source of formaldehyde [52]. Formaldehyde was detected at higher concentration levels in the painting rooms during the summer season in zone 1. SO₂ concentrations, although not statistically significant between zones or seasons, it was found significantly higher outdoor (roof) compared to indoor, possibly from burning of fuel with high sulfur content.

TVOC values reported in the literature are mostly not comparable due to differences in the definition given for a specific range of VOCs, sampling times, measurements, and analysis [53,54]. In this study, TVOCs were divided according to the chemical functional groups of TVOC compounds (aliphatic, aromatic, halogenated, oxygenated). One-way ANOVA did not identify any seasonal variations in monthly average total VOCs in schools. Two-way ANOVA statistical tests revealed that no significant differences in TVOCs existed within the different selected locations in schools; however, significant differences were reported between schools in the two zones with higher average TVOC concentrations in zone 1 schools in comparison to zone 2 schools. Further analysis using Tukey test for comparison of means identified that DAS school within zone 1 had the highest average TVOC concentrations. Several VOCs, of which over 95% were either halogenated or oxygenated, were typically detected indoors in all schools with the most abundant to be methanol, ethanol, and chlorodifluoromethane. The sources of these pollutants were solvents and the most commonly used refrigerant CFC 22. Although CO₂ was considered the most common indoor air quality indicator in the past, when human bio-effluents were considered to be the most important pollutants of indoor

[53], CO₂ has lost this lead because of many discovered pollutants from newly developed products that could contribute to IAQ. As a result, TVOC and its individual compounds should be frequently analyzed in indoor spaces [55]. Regression modeling was not found useful to identify the zone or location equations because grouping of such categories were ordinal and nominal rather than actual scores; there was no intrinsic ordering to the categories in the nominal variable (i.e., code 1 = zone 1, code 2 = zone 2; and code 1 = classroom, code 2 = painting room, code 3 = science room). However, regression was adequate to study seasonal variations; i.e., codes 1, 2, 3, and 4 for fall, winter, spring, and summer, respectively. Both y-intercept and slope coefficients for the regression lines were insignificant; indicating that average total VOC concentrations cannot be well predicted by seasonal variation.

The measured values of CO₂ were recorded on half-hourly and hourly basis. The CO₂ values were higher during full occupancy of students and teachers. Using fully mechanical central air conditioning system in the entire BBD school (most modern school) and in BND teachers' room, demonstrated the lowest CO₂ values. Average CO₂ concentrations for the entire studied classrooms were found lower than neighboring countries' schools in United Arab Emirates (811 ppm vs. 1605 ppm) [56]. Average CO₂ concentration levels were shown to be lower during natural ventilation compared to air-conditioned classrooms in Kuwait (708 ppm vs. 1596 ppm) [57].

The sequential particulate sampler was used to collect both PM₁₀ and PM_{2.5} dust samples based on its selective operation, and the 24-h collected amount was analyzed for trace metal and PAHs. The sample volume for PM_{2.5} was not sufficient enough for trace metal and PAH analysis; therefore, PM₁₀ samples were more frequently collected for further investigation. Iron contamination in PM₁₀ sequential sampling was registered high due to corrosion products from Fe extensive use in door frames, windows, gates, fences, and other amenities being eroded and carried over by dusty air. A similar result for abundant Fe concentration was reported in railway underground subway stations [58]. PM samples from filters of HVAC systems were collected and analyzed for PAHs, PBDEs, and trace metals in both zones. Highest elemental concentrations in AC filters were Fe and Al, specifically at a computer lab in BBD school, although not statistically significant between the two zones. Vanadium, on the other hand, was found at higher concentration levels in zone 2 in comparison to zone 1 since it is considered as the marker element of air pollution emitted from residual oil combustion [59]. Average total PAHs concentrations were 50% higher in zone 1 schools relative to zone 2 schools; however, the average ∑PAHs detected were lower than those found in a similar study [60]. High concentration levels B[a]P triggers attention, since it is considered a carcinogen by WHO [43] and a potential occupational carcinogen by NIOSH [61], and is taken as a marker of the PAH mixture. The PBDEs in dust samples collected from AC filters were dominated by BDE-209 cogener in computer labs due to abundance of wiring installations and electrical components. Similar results by Gevao et al. have been found in dust samples collected from 19 randomly selected cars in Kuwait by Ref. [62] and 70 indoor environments (offices and homes) [63].

Acknowledgment

This work was requested and supported by the Kuwait Ministry of Education (KME) through Kuwait Institute for Scientific Research Project Code EC045C, and was funded by the Kuwait Foundation for the Advancement of Sciences (KFAS), Funding Grant No. 2006-1401-06.

References

- [1] E. Cartieaux, M.A. Rzepka, D. Cuny, Indoor air quality in schools, *Arch. Pediatr.* 18 (2011) 789–796.
- [2] E.E. Nkwacha, R.O. Egejuru, Effects of industrial air pollution on the respiratory health of children, *Int. J. Environ. Sci. Tech.* 5 (2008) 509–516.
- [3] G. Viegi, M. Simoni, A. Scognamiglio, S. Baldacci, F. Pistelli, L. Carrozzi, I. Annesi-Maesano, Indoor air pollution and airway disease, *Int. J. Tuberc. Lung Dis.* 8 (2004) 1401–1415.
- [4] G.D. Gennaro, P.R. Dambruoso, A.D. Loiotile, A.D. Gilio, P. Giungato, M. Tutino, A. Marzocca, A. Mazzone, J. Palmisani, F. Porcelli, Indoor air quality in schools, *Environ. Chem. Lett.* 12 (2014) 467–482.
- [5] J.M. Daisey, W.J. Angell, M.G. Apte, Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information, *Indoor Air* 13 (2003) 53–64.
- [6] T.M. Vincent, Indoor air quality in schools. Report, Educational Resources Information Center (ERIC), Texas Institute for the Indoor Environment, University of Texas, 2000.
- [7] D.J. Clements-Croome, H.B. Awbi, Z. Bako-Biro, N. Kochhar, M. Williams, Ventilation rates in schools, *Build. Environ.* 43 (2008) 362–367.
- [8] M.J. Mendell, G.A. Health, Do poor pollutants and thermal conditions in schools influence student performance? A critical review of the literature, *Indoor Air* 15 (2005) 27–52.
- [9] J. Rosbach, M. Vonk, F. Duijm, J.T. Ginkel, U. Gehring, B.A. Brunekreef, Ventilation intervention study in classrooms to improve indoor air quality: the FRESH study, *Environ. Health* 12 (2013) 110.
- [10] G. Smedje, D. Norback, C. Edling, Subjective indoor air quality in schools in relation to exposure, *Indoor Air* 7 (1997) 143–150.
- [11] J. Madureira, C. Paciencia, C. Pereira, J.P. Teixeira, E. de O Fernandes, Indoor air quality in Portuguese schools: levels and sources of pollutants, *Indoor Air* 26 (2015) 526–537.
- [12] S.C. Lee, M. Chang, Indoor and outdoor air quality investigation at schools in Hong Kong, *Chemosphere* 41 (2000) 109–113.
- [13] H. Fromme, D. Twardella, S. Dietrich, D. Heitmann, R. Schierl, B. Liebl, H. Ruden, Particulate matter in the indoor air of classrooms – exploratory results from Munich and surrounding area, *Atmos. Environ.* 41 (2007) 854–866.
- [14] A. Yousaf, N. Khan, The study of particulate matter concentration in schools in Lahore, *Nat. Environ. Poll. Tech.* 12 (2013) 289–296.
- [15] ASHRAE 62–2001, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, Atlanta, GA, 2011.
- [16] M. Santamouris, A. Synnefa, M. Assimakopoulos, I. Livada, K. Pavlou, M. Papaglastra, N. Gaitani, D. Kolokotsa, V. Assimakopoulos, Experimental investigation of the air flow and indoor carbon dioxide concentration in classrooms with intermittent natural ventilation, *Energy Build.* 40 (2008) 1833–1843.
- [17] A. Synnefa, E. Polichronaki, E. Papagiannopoulou, M. Santamouris, G. Mihalakakou, P. Doukas, P.A. Siskos, E. Bakeas, A. Dremetsika, A. Geranios, A. Delakou, An experimental investigation of the indoor air quality in fifteen school buildings in Athens, Greece, *Int. J. Vent.* 2 (2003) 185–201.
- [18] M. Jovanovic, B. Vucevic, V. Turanjanin, M. Zivkovic, V. Spasojevic, Investigation of indoor and outdoor air quality of the classrooms at a school in Serbia, *Energy* 77 (2004) 42–48.
- [19] S. Almeida, N. Canha, A. Silva, M. Freitas, P. Pegas, M. Alves, M. Evtugina, C. Pio, Children exposure to atmospheric particles in indoor of Lisbon primary schools, *Atmos. Environ.* 45 (2011) 7594–7599.
- [20] W. Yang, J. Sohn, J. Kim, B. Son, J. Park, Indoor air quality investigation according to age of the school buildings in Korea, *J. Environ. Manage* 90 (2009) 348–354.
- [21] M. Verrielle, C. Schoemaeker, B. Hanoune, N. Leclerc, S. Germain, V. Gaudion, N. Locoge, The MERMAID study: indoor and outdoor average pollutant concentrations in 10 low-energy school buildings in France, *Indoor Air* 26 (2016) 702–713.
- [22] R. Meiningerhaus, A. Kouniali, C. Mandin, A. Ciolella, Risk assessment of sensory irritants in Indoor air - a case study in a French School, *Environ. Int.* 28 (2003) 553–557.
- [23] I. Annesi-Maesano, F. Lavaud, C. Raheison, C. Kopferschmitt, F. Blay, D. Charpin, D. Caillaud, Indoor air quality and sources in schools and related health effects, *J. Toxicol. Environ. Health B Crit. Rev.* 16 (2013) 491–550.
- [24] J. Madureira, M.C. Alvim-Ferraz, S. Rodrigues, C. Goncalves, M.C. Azevedo, E. Pinto, O. Mayan, Indoor air quality in schools and health symptoms among Portuguese teachers, *Hum. Ecol. Risk Assess.* 15 (2009) 159–169.
- [25] M. Simoni, I. Annesi-Maesano, T. Sigsgaard, D. Norback, G. Wieslander, W. Nystad, M. Canciani, P. Sestini, G. Viegi, School indoor air quality related to dry cough, rhinitis and nasal patency in children, *Eur. Respir. J.* 35 (2010) 742–749.
- [26] M. Elbayoumi, N. Ramlı, N. Yusof, W. Al-Madhoun, The effect of seasonal variation on indoor and outdoor carbon monoxide concentrations in Eastern Mediterranean climate, *Atmos. Poll. Res.* 5 (2014) 315–324.
- [27] A. Chaloulakou, I. Mavroidis, Comparison of indoor and outdoor concentrations of CO at a public school: evaluation of an indoor air quality model, *Atmos. Environ.* 36 (2002) 1769–1781.
- [28] P. Wargocki, J. Sundell, W. Bischof, G. Brundrett, P.O. Fanger, F. Gyntelberg, S.O. Hanssen, P. Harrison, A. Pickering, O. Seppanen, Ventilation and health in indoor environments: report from a european multidisciplinary scientific consensus meeting (EUROVEN), *Indoor Air* 12 (2002) 113–128.
- [29] M. Branis, P. Rezacova, M. Domasova, The effect of outdoor air and indoor human activity on mass concentrations of PM₁₀, PM_{2.5}, and PM₁ in a classroom, *Environ. Res.* 99 (2005) 143–149.
- [30] O. Poupard, P. Blondeau, V. Lordache, F. Allard, Statistical analysis of parameters influencing the relationship between outdoor and indoor air quality in schools, *Atmos. Environ.* 39 (2005) 2071–2080.
- [31] H.K. Lai, M. Kendall, H. Ferrier, I. Lindup, S. Alm, O. Hanninen, M. Jantunen, P. Mathys, R. Colvile, M.R. Ashmore, P. Cullinan, M.J. Nieuwenhuijsen, Personal exposure and microenvironment concentrations of PM_{2.5}, VOC, NO₂ and CO in Oxford UK, *Atmos. Environ.* 38 (2004) 6399–6410.
- [32] M.S. Zuraimi, C.A. Roulet, K.W. Tham, S.C. Sekhar, K.W. Cheong, N.H. Wong, K.H. Lee, A comparative study of VOCs in Singapore and European office buildings, *Build Environ* 41 (2006) 316–329.
- [33] J. Al-Hubail, A. Al-Temeemi, Assessment of school air quality in a desert climate, *Build. Environ.* 94 (2015) 569–579.
- [34] N.A. Alkhamees, Practices and symptoms related to indoor air pollution reported by Kuwaiti students, teachers and university faculty, *Int. J. Health Prom. Educ.* 52 (2014) 163–169.
- [35] A. Abal, A. Ayeed, P. Nair, M. Mosawi, N. Behbehani, Factors responsible for asthma and rhinitis among Kuwaiti schoolchildren, *Med. Prin Pract.* 19 (2010) 295–298.
- [36] E. Al-Bassam, V. Popov, A. Khan, Air quality in vicinity of a government school in Kuwait, *WIT Transactions on Ecology and the Environment, Air Pollut.* XV 101 (2007).
- [37] W.S. Bouhamra, A. Elkilani, Estimation of optimum requirements for indoor air quality and energy consumptions in some residences in Kuwait, *Environ. Int.* 27 (2001) 443–447.
- [38] W.S. Bouhamra, Estimation of volatile organic compounds in Kuwaiti houses after the Gulf war, *Environ. Pollut.* 90 (1995) 121–125.
- [39] T. Saeed, N. Ahmad, A. Al-Omair, M. Beg, Comparison of the levels of PAHs present in the dust collected from different residential areas of Kuwait, 1991–1996, *Environ. Int.* 24 (1998) 197–203.
- [40] W.S. Bouhamra, S.S. BuHamra, M.S. Thomsom, Determination of volatile organic compounds in indoor and ambient air of residences in Kuwait, *Environ. Int.* 23 (1997) 197–204.
- [41] A. Elkilani, W.S. Bouhamra, Estimation of optimum requirements for indoor air quality and energy consumption in some residences in Kuwait, *Environ. Int.* 27 (2001) 443–447.
- [42] L. Al-Awadi, M. Al-Rashidi, A.R. Khan, S. Neelamani, A. Ba, A. Al-Dabbous, M. Halaleh, M. Abdullah, M. Al-Qasimi, M. Al-Saleh, A. Ali, Z. Al-Ballam, Assessment of Organic Pollutant Levels in Selected Schools vol. II, Kuwait Institute for Scientific Research (KISR), 2012. Report No. EC045C.
- [43] WHO, Development of WHO Guidelines for Indoor Air Quality, World Health Organization (WHO) Regional Office for Europe, Bonn, Germany, 2006a.
- [44] EPA Compendium Method TO-14A, Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Specially Prepared Canisters with Subsequent Analysis by Gas Chromatography, Center for Environmental Research Information, Office of Research and Development, Cincinnati, Ohio, 1999.
- [45] A.R. Khan, A.E. Hajjah, A. Ramadan, L. Al-Awadi, B. Gevao, G. Mahaswari, D. Al-Nakeeb, F. Al-Ghimlas, Indoor Air Quality and Environmental Assessment Study for the New Corporate Oil Sector Complex vol. 8078, Kuwait Institute for Scientific Research (KISR), 2006. Report No. KISR.
- [46] Moopam, in: third ed. Manual of Oceanographic Observations and Pollutant Analyses Methods, Regional Organization for the Protection of the Marine Environment (ROPME), VI 20, 1999. Kuwait.
- [47] EPA 610, Method 610: Polynuclear Aromatic Hydrocarbons, USEPA, 1984.
- [48] EPA 8272, Validated Test Method 8272: Parent and Alkyl Polycyclic Aromatics in Sediment Pore Water by Solid-phase Microextraction and Gas Chromatography/Mass Spectrometry in Selected Ion Monitoring Mode, USEPA, 2007.
- [49] WHO, WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update – Summary of Risk Assessment, WHO, Geneva, Switzerland, 2006b.
- [50] WHO, Methods for Monitoring Indoor Air Quality in School, WHO Regional Office for Europe, Bonn, Germany, 2011.
- [51] OSHA, OSHA Technical Manual: Indoor Air Quality Investigation, Section III, Chapter 2, OSHA, US, Department of Labor, Washington, DC, 1999.
- [52] WHO, Air Quality Guidelines for Europe, WHO Regional Office for Europe, Copenhagen, 1987.
- [53] WHO, Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations, European Commission, JRC, Luxembourg, 1997.
- [54] G. Zhang, J. Spickett, K. Rumchev, A.H. Lee, A. Stick, Indoor environmental quality in a “low allergen” school and three standard primary schools in Western Australia, *Indoor Air* 16 (2006) 74–80.
- [55] S.K. Brown, M.R. Sim, M.J. Abramson, C.N. Gray, Concentrations of volatile organic compounds in indoor air - a review, *Indoor Air* 4 (1994) 123–134.
- [56] M.O. Fadeyi, K. Alkhaja, M. Sulayem, B. Abu-Hijleh, Evaluation of indoor environmental quality conditions in elementary schools' classrooms, *Front. Arch. Res.* 3 (2014) 166–177.
- [57] K. Al-Rashidi, D. Loveday, N. Al-Mutwa, Impact of ventilation modes on carbon dioxide concentration levels in Kuwait Classrooms, *Energy Build.* 47 (2012) 540–549.
- [58] H. Kamani, M. Hoseini, M. SeyedSalehi, Y. Mahdavi, J. Jaafari, G.H. Safari,

- Concentration and characterization of airborne particles in Tehran's subway system, *Environ. Sci. Pollut. R.* 21 (2014) 7319–7328.
- [59] M. Dunder, Vanadium concentrations in settled outdoor dust particles, *Environ. Monit. Assess.* 123 (2006) 345–350.
- [60] M.F. Yassin, N.S. Alhajeri, M.A. Kassem, Polycyclic aromatic hydrocarbons collected from indoor built environments on heating, ventilation and air conditioning dust filters, *Indoor Built Environ* 25 (2016) 137–150.
- [61] NIOSH, Coal Tar Pitch Volatiles, NIOSH Pocket Guide to Chemical Hazards, Center for Disease Control and Prevention, 2016. Atlanta, GA.
- [62] B. Gevao, F. Shammari, L.N. Ali, Polybrominated diphenyl ether levels in dust collected from cars in Kuwait: implications for human exposure, *Indoor Built Environ.* 25 (2016) 106–113.
- [63] B. Gevao, M. Al-Bahloul, A. Al-Ghadban, L. Ali, A. Al-Omair, M. Helaleh, K. Al-Matrouk, J. Zafar, Polybrominated diphenyl ethers in indoor air in Kuwait: implications for human exposure, *Atmos. Environ.* 40 (2006) 1419–1426.