International Journal of Environmental Science and Technology (2019) 16:2831–2838
https://doi.org/10.1007/s13762-018-1869-6

ORIGINAL PAPER

Indoor and outdoor air concentrations of volatile organic compounds in schools within different urban areas

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Received: 4 July 2017 / Revised: 12 October 2017 / Accepted: 13 June 2018 / Published online: 23 June 2018

Abstract
This study included nine schools which were selected from three different areas (industrial, traffic, and residential) of Kuwait. Three schools were chosen from each area to represent elementary, middle, and secondary levels. Samples of indoor volatile organic compounds (VOCs) were collected using canisters placed in one classroom in each school in addition to outdoor VOCs captured in canisters placed at the roof of one chosen school among the three studied at each area. The VOCs levels were monitored during the weekdays and weekends (schools closed) over a period of 2 months. The results showed higher VOCs concentrations in indoor than in outdoor samples in all schools studied at the three areas during both the weekdays and the weekends, irrespective of the level of schooling. Indoor VOCs concentrations were less than 200 ppbv in all schools, with relatively higher levels recorded in schools located in the industrial area reaching 681 ppbv since the indoor air quality is influenced by that of outdoor. The total (indoor and outdoor) levels of VOCs measured during the weekdays were higher than those detected in the weekends in both the traffic and industrial areas, whereas the opposite was observed in the residential area due to its increased weekend traffic density. Percentage composition of VOCs in air samples indicated domination of halogenated and oxygenated components compared to aliphatic and aromatic constituents. The affected schools should increase ventilation rates and install devices to purify the indoor air to ensure healthy environment for students, teachers, and employees at schools.

Keywords Indoor air quality · Indoor/outdoor ratio · Schools · Volatile organic compounds

Introduction

Volatile organic compounds, sometimes referred to as VOCs, are organic compounds that easily become vapors or gases. Along with carbon, they contain elements such as hydrogen, oxygen, fluorine, chlorine, bromine, sulfur, and/or nitrogen. Volatile organic compounds are emitted in substantial quantities from both biogenic and anthropogenic sources and have a major influence on the chemistry of the lower atmosphere. It is well established that the gas-phase degradation of VOCs plays an important role in the generation of a variety of secondary pollutants, which may have a harmful effect on human health and on the environment (Saunders et al. 2003). VOCs are of concern as both indoor air pollutants and outdoor air pollutants. However, the emphasis of that concern outdoors is different from indoors. The main concern indoors is the potential for VOCs to adversely impact the health of people that are exposed. While VOCs can also be a health concern outdoors, EPA regulates VOCs outdoors mainly because of their ability to create photochemical smog under certain conditions. The composition of VOCs makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure. The higher the volatility (lower the boiling point), the more likely the compound will be emitted from a product or surface into the air.

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Emission of VOCs is particularly important in places where humans spend time together in confined area. Schools are good examples of such areas. The most common indoor sources of VOCs are wall paints, cosmetics, pens and pencils, cleaning supplies, pesticides, computers, printers, labtops, televisions, monitors, etc. (Almeida et al. 2011). School buildings may be the most significant places among all buildings categories due to the high density of students, teachers, workers who occupy the place for a long period of time during the day. The high density of people inside the building means a high traffic level at the outside, which affects the air purity that flows into the rooms and classes. Poor school maintenance should be also taken into consideration. On the other hand, odors and cleaning products used to wipe all the dust and sweepings from the floors, doors, tables, chairs, and windows contain a fine amount of VOCs that adversely affect human health (Almeida et al. 2011). Castorina et al. (2016) reported that alcohols were the most highly emitted class of VOCs from permanent and dry erase markers used in preschools, schools, and homes. Lee et al. (2012) found that total VOCs and toluene concentration in a new school building highly exceeded the standard level right after construction but were significantly decreased for 6 months after construction. Meanwhile, Babayigit et al. (2014) claimed that indoor health assessment should be done for students and the school's staff to guarantee their safety. Physical, mental, social, and health status should be targeted for not only students, but also the teachers and school staff. The point of risk caused by VOCs varies depending on the mixture contents, concentration, amount, types, and the time of exposure. Nevertheless, the new designs and structures of school buildings and the technology used may create poor air exchange. Therefore, chemicals emitted inside the rooms by cleaning products, furniture, goods, food, paints, pens, markers, microorganisms, and electrical devices have become more frightening (Babayigit et al. 2014).

Exposure to VOCs has been an indoor environmental quality concern in schools. Children are more sensitive to pollutants than adults and yet they spend longer times in school environments where they are exposed to unknown levels of indoor pollutants (de Gennaro et al. 2013). Studies conducted on schools in different countries have shown different levels of VOCs detected in classrooms in Michigan, USA (Batterman and Godwin 2007; Zhong et al. 2017), in Kocaeli, Turkey (Arslanba and Pekey 2008), in eleven European cities (Geiss et al. 2011), in Portugal (Agostinho et al. 2012) and in Italy (de Gennaro et al. 2013). Some classrooms showed a very low level of VOCs, while others showed either a high indoor pollution or a high outdoor contribution. The outdoor concentrations are usually lower than the indoor concentrations for each school (de Gennaro et al. 2013).

The literature does not include any studies on levels of VOCs in schools in the state of Kuwait. Therefore, this study was conducted to measure VOCs concentrations in schools that were chosen to include areas with different urbanization and traffic density characteristics in Kuwait.

Materials and methods

Study area

Three main urban areas in Kuwait were selected for this study, namely Ali Sabah Al-Salem as an industrial area, Al-Farwaniya as a traffic area, and Abdullah Al-Mubarak being a residential area. From each area, three schools were chosen to collect the indoor samples. Tested schools were built or renovated in the past 20 years. Meanwhile, an outdoor sample was also collected from the roof of one school in each area to get the background VOCs concentration at each site. The sampling was carried out during the month of November and December 2015 at the selected locations when the schools were open during the school hours with students, teachers and staff present.

Ali Sabah Al-Salem Residential Area (ASA) formerly called Um Al-Hayman is located to the south of Kuwait and is considered as a highly polluted area since it is directly downwind from the large industrial area, which includes petrochemicals, power stations, industrial zones at Mina Abdullah area (which is just across the street from ASA) and other private sectors that sprung up around the Burgan oil fields. Al-Shuaiba and Mina Abdullah's' refineries are located on Fahaheel highway. Oil refineries, landfills, chemical plants are also there. Al-Farwaniya (FWNA) region is considered as the most populous of all the governorates in Kuwait. It houses the two biggest shopping malls in Kuwait, various commercial centers, the Airport, and the busiest roads of Kuwait (4th ring road and Old Airport Road). This in turn results into huge traffic in this area. Abdullah Al-Mubarak (AM) region also known as West Jleeb Al-Shuyoukh is a suburban area in Kuwait. It is mostly a residential area with more community dwellings and aesthetic amenities. The schools tested in each area, from which air samples were collected for VOCs, are shown in Table 1, along with the main characteristics of the schools and the sampling area.

Air sampling

Air sampling was performed using canisters with CS1200 flow regulator attached to the canisters for 24-h and controlled 8-h sampling. At each area, the canisters were deployed in duplicates. Two canisters were connected together to a single inlet and were allowed to sample for a stipulated time say 8 and 24 h. Thus, at each sampling site

Table 1 Characteristics of the area monitored and the selected schools

Monitored site	Type of school	Description
Ali Sabah Al-Salem (ASA)	Elementary school	Abdulrahman Al-Dakhil elementary school is located beside a roundabout in ASA. It is close to two trafficated roads King Fahad highway by 1.6 km and Fahaheel highway by 1.70 km
	Middle school	Abdullah Ibn Al Zubair middle school is also close to two trafficated roads King Fahad highway by 0.97 km and Fahaheel highway by 2.00 km
	High school	Omar Ibn Al Khatab high school is close to two trafficated roads King Fahad highway by 1.70 km and Fahaheel highway by 1.4 km. At this particular school, canisters were placed at the Arabic department. (To avoid any damage to the canisters, because students were very naughty.) This particular department was chosen because the number of teachers at it equals the normal number of students per class which is 20. A smell of coffee was obvious at the department. This high school is away from the primary school by 0.3 km
Al-Farwaniya (FWNA)	Elementary school	Al Muthanna elementary school is in the middle of the crowd and surrounded by houses. It is trapped by cars from all around
	Middle school	AlMulla Abdullaziz Nasser Al Anjary middle school is also in the middle of the crowd and surrounded by houses. It is trapped by cars from all around too
	High school	Al Mubarakya high school is located in front of a (Hookah cafe—Metro mall—Sandwiches restaurants—sweets store—Kuwait credit fund bank) and a car garage which is next to the school (same line). Since the school is located in Al-Farwaniya, it is also surrounded by traffic from all around
Abdullah Al-Mubarak (AM)	Elementary school	Qatada Ibn Nu'man elementary school is located on a roundabout and surrounded by houses
	Middle school	Salamah bint Qays Al Ashjaee middle school shares its parking with the cooperative—student center—and Starbucks cafe. It is also surrounded by homes from the back
	High school	Al Shojaa Ibn Al Aslam high school is located on a roundabout and surrounded by houses

a set of two duplicates, i.e., four canisters, were deployed, one set was sampling for 24 h and the other set for 8 h. The sample collection time was fixed and was programmed and controlled to start at 7.00 a.m. and continuously sampled for the fixed time frame. This sampling schedule assured a generalized pattern in the sample collection as well as ensured effective interpretation and precise quantification of the pollutant concentration from the collected samples. Further, the sampling pattern covered the weekdays and the weekends (schools closed) which enabled the comparison of pollutant concentration on those days.

Air analysis

The whole air samples were analyzed for 72 VOCs, which were grouped under four separate chemical classes as 9 aliphatic hydrocarbons (HCs), 8 aromatic hydrocarbons (AHCs) 29 halogenated hydrocarbons (HHCs), and 26 oxygenated hydrocarbons (OHCs). The capabilities and limitations of the sampling and analytical methods should be considered while interpreting the ambient air monitoring data. To judge and characterize the present study, a combination of the two EPA approved methods TO14 A and TO15 was used (USEPA 1999). Ambient VOC samples were analyzed using gas chromatography with flame ionization detector (GC/FID). The air samples from the canister were analyzed using a combined cryogenic concentrator Entech instrument model 7100A with Agilent instrument model 7890A GC/FID analyzer. The cryogenically trapped samples were desorbed from − 1500 to 1800 °C and then focused at − 1500 °C in the focusing trap for GC/FID analysis. The eluting VOC components from the GC column were further detected by the FID wherein a hydrogen and air flame chemically ionize the organically bound carbon atoms of the sample and produced electrical signals that were subsequently measured. The compounds were qualitatively identified by Agilent Chem. Station software and quantitatively estimated with 50 ppbv standards (Air Environmental Inc.).

Results and discussion

The following sections present the results obtained from schools in each studied area and included the average values of the total VOC concentrations measured from the indoor (I) as well as the outdoor (O) samples collected from the selected locations/schools at each of the three areas studied over the weekdays and consecutive weekends. In addition, they show the breakdown of VOCs components as aliphatic, aromatic, halogenated, and oxygenated groups.

Ali Sabah Al-Salem (ASA) region

Variations in the mean value of the total VOCs measured over the entire site of ASA are displayed in Fig. 1. The mean values of the total VOCs concentrations measured from the indoor as well as the outdoor samples collected from the selected locations/schools at ASA over the weekdays and

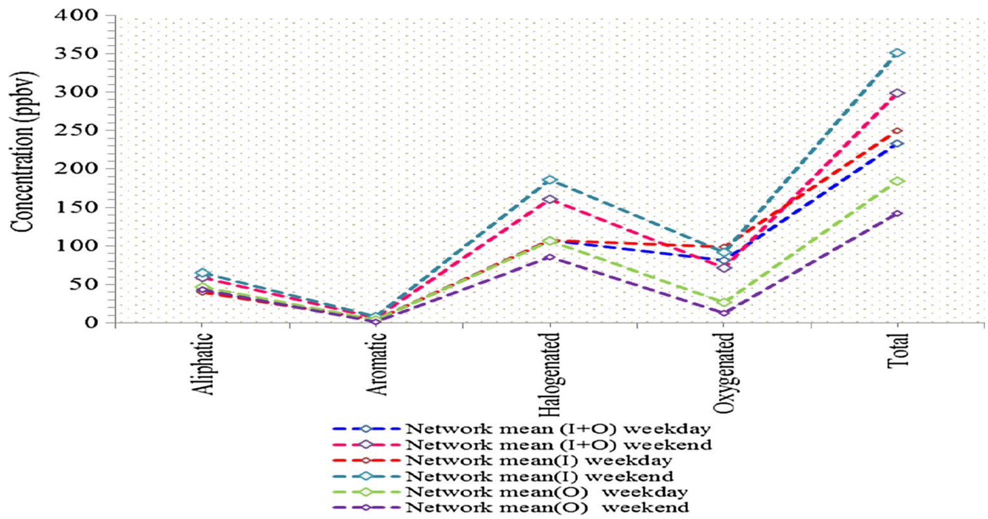


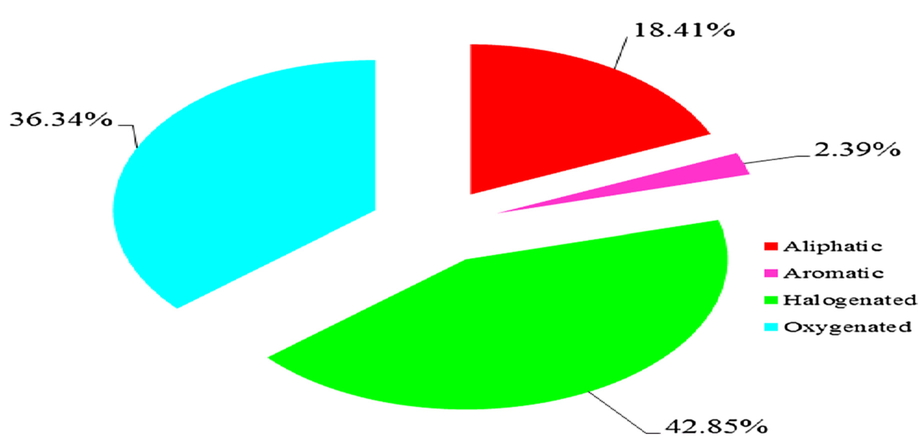
Fig. 1 Mean concentrations of VOCs in the I and O samples collected from ASA

consecutive weekends fall below 400 ppbv. The results reflected the conditions and the duration of the sampling. Meanwhile, the highest total VOCs concentration measured over the entire site on the sampling days was below 681 ppbv. It is interesting to note that all the group concentrations followed the same pattern, showing higher concentrations during the weekday than for the weekend and that the indoor VOCs concentrations are higher than those measured outdoor. This was true irrespective of the level of schooling (elementary, middle, or high schools).

A detailed analysis of the spatial variation of total VOCs with a classification between groups was conducted to define the trend and variations of the VOCs. The VOCs were classified mainly into four groups namely hydrocarbons, aromatics, halogenated, and oxygenated. An example is shown in Fig. 2 indicating that the majority of the VOCs were in the halogenated and the oxygenated forms. The VOCs components during the sampling days showed a clear entry from the outdoor into the indoor, and their concentrations were further increased by those resulting from activities involved in the school environment on the same days. To further support this observation, the indoor (I)-to-outdoor (O) concentration ratio was calculated for the components to see whether these compounds originate from the outdoor sources infiltrating to the indoor environment. The I/O ratios obtained were 1.0 ± 0.5 indicating that the VOC is mainly emitted from an outdoor source, whereas a high I/O VOC ratio, usually > 5.0, is emitted primarily from indoor sources (Al-Khulaif et al. 2014). While looking at other results obtained comparing the I/O indicator values, it can be postulated that the variation in group component concentrations in the indoor environment is indirectly influenced by the composition of these components outdoors.

Among the halogenated groups that showed up during the sampling were 1,2-dichlorotetrafluoroethane and vinyl chloride, and their concentrations were higher during the weekend compared to the weekday. Among the oxygenated components, ketones like acetone, 2-pentanone, 4-methyl-2-pentanone and alcohols like ethanol, methanol and 2-propanol were found at higher concentrations and these were

Fig. 2 Average percentage composition of the 24 h VOC's collected from middle school in ASA on November 24, 2015 (weekday)



purely generated from the indoor activities as their concentrations were very low in the outdoor environment. Even though aldehydes were detected in most of the samples, their concentrations were low and inconsistent.

The aliphatic, aromatic, and the halogenated concentrations measured from indoor air of the schools are actually comparable to those values measured from the outdoor samples. Apparently, a contribution of the background outdoor emissions to the indoor levels of these components is evident from the results. Furthermore, an increase in the concentration of each of these components in the indoor spaces can be due to the activities carried out at classrooms of that particular location. The trend in the variation of the VOC concentrations over the ASA area and its level in the selected indoor spaces were studied by analyzing each location in detail. Figure 3 shows an example of values obtained from a middle school. It was evident that the total concentration of the VOCs in the weekend was lower than during the weekday except for the high school.

Farwaniya (FWNA) region

The variations in the mean concentration of the VOCs at the FWNA region are presented in Fig. 4 which shows that the total VOCs concentration from the schools in the FWNA region reached to an average value of 450 ppbv during the sampling days. The mean value was higher during the weekday compared to the weekend as the VOC concentration from the (I) is elevated during the weekday which resulted in an overall increase in the same. The mean value of the (O) samples during the weekday as well as that of the (I) and (O) samples during the weekend was very low (below 150 ppbv). Similar tends were observed at schools in this region as in the ASA, but values were different. This is also true for the average percentage composition of the indoor VOCs showing that the oxygenated VOCs were more dominant (Fig. 5). Meanwhile from the (I) to (O) ratio calculated, the components with high indoor predominance were aromatics as well as oxygenated groups (Fig. 6).

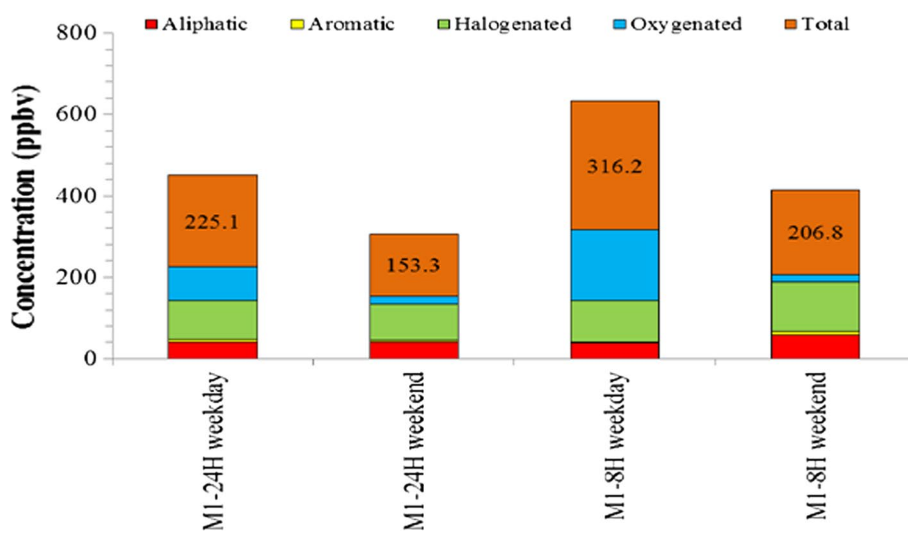


Fig. 3 Variations in the concentration of VOC's over weekdays and weekends at a middle school in Ali Sabah Al-Salem Area

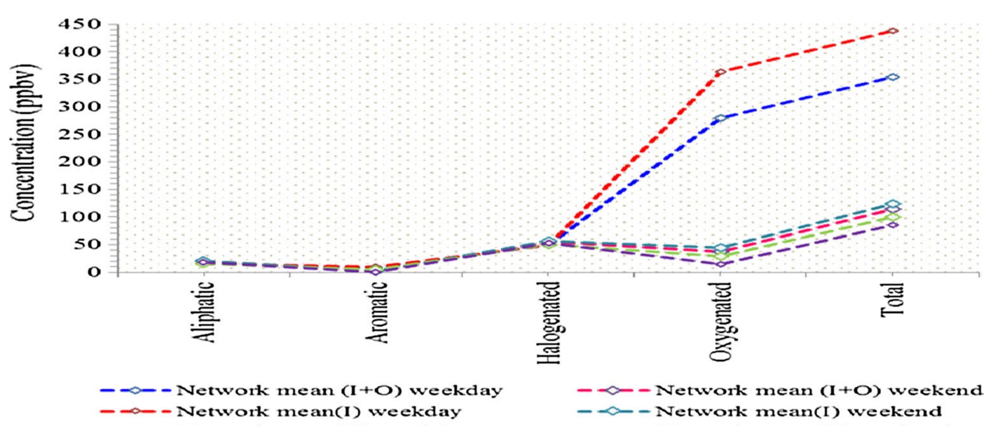


Fig. 4 Mean concentration of VOC's measured from schools at Farwaniya Area

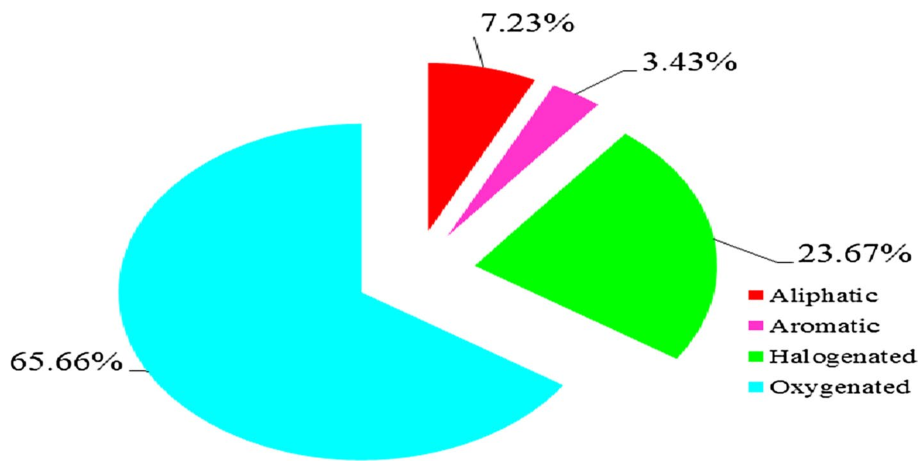


Fig. 5 Average percentage composition of the 24 h VOC's collected from middle school in Farwaniya on December 1, 2015 (weekday)

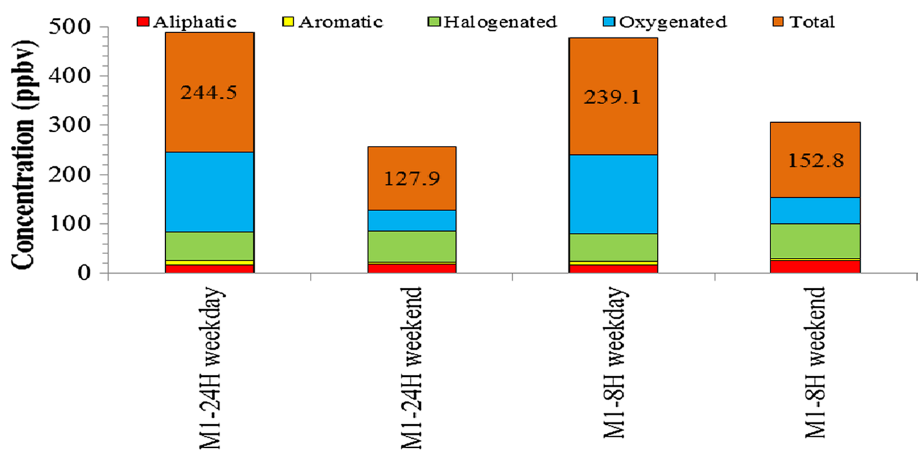


Fig. 6 Variations in the concentration of VOC's over weekdays and weekends at middle school in Farwaniya Area

Abdulla Mubarak (AM) region

The VOCs concentrations in indoor samples were higher than those in outdoor samples in schools at this area. However, unlike the other areas sampled, the mean VOC's concentration was higher during the weekends compared to the weekdays in the indoor as well as the outdoor samples, possibly due to the high traffic movement during the weekend at this residential area. During the weekdays, the mean value of the VOC's concentrations was below 182 ppbv, with the maximum concentration of the group components shown by the oxygenated group in the indoor samples (Fig. 7). The weekend samples showed an elevated level in the concentration of aliphatic as well as the halogenated components during the weekend in indoor as well as outdoor samples which are considered to be the significant components that increase the overall VOC level at this location (Figs. 8, 9).

Conclusion

The results showed higher VOCs concentrations in indoor than in outdoor (ambient) air samples in all the school studied in three urban areas during both the weekdays and the weekends. This was true irrespective of the level of schooling (elementary, middle, or secondary). Indoor VOCs concentrations were less than 200 ppbv in all schools studied, with relatively higher levels recorded in schools located in the industrial area reaching 681 ppbv, since the indoor air quality is influenced by that of the outdoor. The total (indoor and outdoor) levels of VOCs measured during the weekdays were higher than those detected in the weekends in both the traffic and industrial areas, whereas the opposite was observed in the residential area possibly due to increased traffic density in this area during the weekend. Percentage composition of

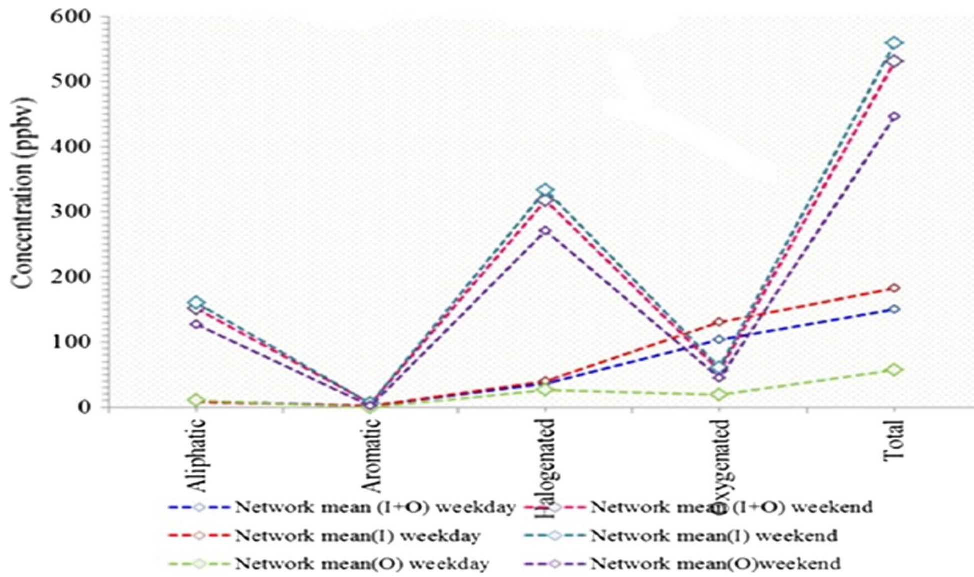


Fig. 7 Mean concentration of VOC's measured from schools at Abdullah Mubarak Area

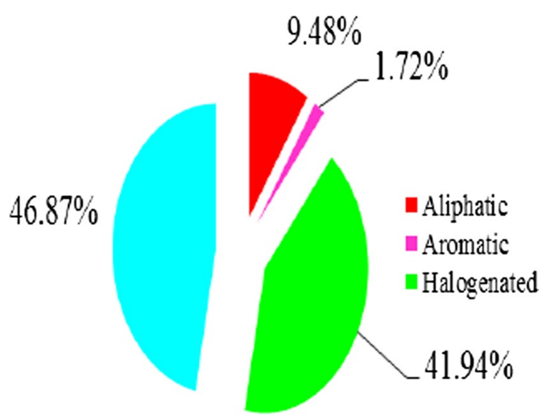


Fig. 8 Average percentage composition of the 24 h VOC's collected from the middle school in Abdullah Mubarak area on December 9, 2015 (weekday)

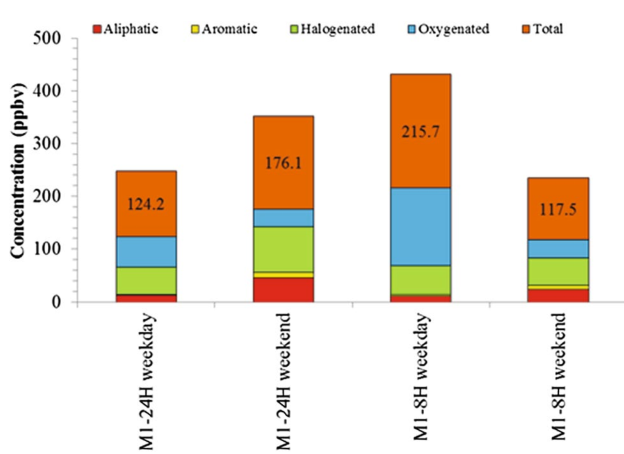


Fig. 9 Variations in the concentration of VOC's over weekdays and weekends at the middle school in Abdullah Mubarak Area

VOCs in air samples indicated domination of halogenated and oxygenated components as compared to aliphatic and aromatic constituents. The indoor/outdoor (I/O) ratio of VOCs calculated indicates that the VOCs components with high indoor predominance were aromatics as well as oxygenated groups. It is recommended that affected schools would increase ventilation rates and install devices to purify the indoor air and ensure healthy environment for students, teachers, and employees at schools.

Acknowledgements The authors would like to thank Mrs. Anju Muraleedharan of the Environmental Pollution and Climate Program research laboratory in the Environment and Life Sciences Research Center at Kuwait Institute for Scientific Research (KISR) who conducted the air analysis. The financial support received from the College of Graduate Studies, Kuwait University, and the permission granted by KISR to perform the air analysis are very much appreciated.

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