International Journal of Environmental Science and Toxicology Research (ISSN: 2408-7262) Vol. 4(3) pp. 44-53, April, 2016
Available online http://www.internationalinventjournals.org/journals/IJESTR

Full Length Research Paper

Indoor exposure from building materials: A field study of Tamale, Northern Ghana

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Received 20 March, 2016; Accepted 5 April, 2016

The present study has been conducted within the framework of assessing the exposure to emitted compounds in indoor air around Tamale and its environs. Fieldwork in five (5) locations (within the Central Business District CBD and some suburban locations namely Kanvili, Vittin, Kalpohin and Sagnarigu) were carried out. These campaigns covered seasonal concentration measurements in two (2) public/commercial buildings and two (3) private houses in each location. BTEX, terpenes, and carbonyls were measured using passive sampling in two sites inside the building and one outside. VOC emission measurements on selected building material have also been performed using Field and Laboratory Emission Cell (FLEC). The results on indoor concentrations for compounds such as formaldehyde (1.2-62.6 μg/m^3), acetaldehyde (0.7-41.6 μg/m^3), toluene (0.9-163.5 μg/m^3), xylenes (0.2-177.5 μgm^3) and acetone (2.8-308.8 μg/m^3) have shown diversity and relatively significant indoor sources depending on the building type, age etc. Indoor concentrations of these substances vary depending on the building age and type. The percentage of approximately 46% of the indoor air quality levels originated from building materials.

Keywords: Building materials emissions, Volatile Organic Compounds (VOCs), Indoor Air Quality (IAQ), Field and Laboratory Emission Cell (FLEC).

INTRODUCTION

Many studies have demonstrated that building materials can be significant emission sources or sink Volatile Organic Compounds (VOCs), which may affect the indoor concentration (Knudsen et al., 1999). VOCs originate from both indoor and outdoor sources; they are of particular concern due to their potential negative impact on human health (Marchland et al., 2006). Formaldehyde and benzene, for example, are some of the most studied pollutants since they are classified in Group 1 of human carcinogens by the International Agency for Research on Cancer (IARC, 2004). For many of these chemicals, the risk on human health and comfort is almost unknown and difficult to predict because of the lack of toxicological data. In the frame of the INDEX(Indoor Exposure Limits) project (Kotzias et al., 2005) the existing knowledge worldwide has been assessed in terms of type and levels of chemicals in indoor air, as well as, the available toxicological information. It was concluded that VOCs such as benzene, formaldehyde, acetaldehyde, toluene and xylenes have to be considered as priority pollutants with respect to their health effects. On the other hand, chemicals such as limonene and a-pinene require further research with regard to human exposure or dose response and effects. Reported indoor concentration of individual VOCs are generally below 50μg/m^3, with most below 5μg/m^3 (Wolkoff et al., 2006). Indoor air concentrations for formaldehyde varied between 38 and 310 μg/m^3 (Schleibinger et al., 2001). Mean values for formaldehyde's had a range between 93-134μgm^3 and 86- 58μg/m^3 in respectively new and old buildings, (Park and Ikeda, 2006). Additionally, typical European indoor exposure concentrations for xylenes, acetaldehyde and terpenes varied between 2-37μg/m^3, 10-18μ/gm^3 and 6-83μg/m^3, respectively (Kotzias et al., 2009).

Combined indoor/outdoor air quality measurements have shown that significant VOC sources exist indoors. For example the aldehyde concentrations are usually 2-10 times higher than outdoors (Marchland et al., 2006). It has been stated that in renovated or newly completed buildings, the VOCs concentration levels are often several times higher (Kim et al., 2006). The main sources of aldehydes in homes include building materials, hardwood, plywood, laminate floorings, adhesives, paints and varnishes and in some cases they are products of ozone- initiated reactions (Marchland et al., 2006; Wechsler et al., 1992). For example, interior coatings can increase indoor air pollution due to VOC emissions (Kwok et al., 2003). Some of the major VOCs emitted from an oil-based varnish were ethylbenzene, m,p, o-xylene and formaldehyde (McCrillis et al., 1999).

Formaldehyde is known to be released by press wood products used in home building construction such as Medium-Density Fibreboard (MDF), and paneling and products made by urea- formaldehyde resins (Kelly et al.,1999). The contribution of building materials and furnishing to indoor air pollution has been demonstrated by a study of VOC emissions in newly built, unoccupied houses. (Yu and Crump, 1999). The sampling of VOCs in indoor air has shown that the contribution of building material emissions was significant during the first six months.

Although, numerous studies have investigated the levels of indoor air pollutants and emission measurements in laboratories, research on systematic in- field studies, linking the VOC concentrations to their indoor sources is rather limited (Jarnstrom et al., 2007). The primary aim of the present work is to characterize building materials as indoor VOC emission sources by conducting indoor concentration and emission measurements in houses and public buildings- including schools, across the city Tamale. The measurements cover mainly carbonyls, BTEX (B-Benzene, T-Toluene E-Ethylbenzene, X-Xylenes) and terpenes with emphasis on the abovementioned priority compounds.

METHODOLOGY

Measurements were carried out between 2013 to 2014 in five different locations during the rainy and dry seasons. Measurements were conducted in four buildings per location; one public building (in some cases 2), one school and two private houses. Three sites per building were selected, two indoors and one outdoor (e.g. for a public building: office, hall, outdoor). The buildings were selected according to the following criteria: (1) the age (less than two years) (2) the last reconstruction or renovation, (3) the position of the building (urban sites preferred) and (4) the building's access (Missia et al., 2010). "Indoor and outdoor VOC measurements were carried for a period of one week by out using Radiello passive samplers (charcoal/carbograph type for VOCs and DNPH-covered for carbonyl compounds). At indoor locations, the passive sampling equipment was placed approximately 1.5 m above the ground, either on tables or other furniture". (Missia et al., 2010).

Outdoor sampling locations were chosen in order to avoid significant point sources of pollution, such as kitchens, and exhaust air vents. Selected building material in-field emissions measurements were also performed by using the Field and Laboratory Emission Cell (FLEC). The FLEC measurements were carried out according to ENV standards (ENV 13419, 2003; ASTM 5116, 1997). Tenax TA for BTEX and its homologues and DNPH cartridges for carbonyls were used as absorption tubes for the FLEC experiments. Sample analyses were also conducted according to International Standards Organization (ISO 16000-3, 2001; ISO 16000-6, 2004). Various quality control tools were used in order to ensure that adequate laboratory performance was maintained. These included control charts for standard solutions, analysis of control standards as unknowns and analysis of Certified Reference Materials (CRM562 Aromatic hydrocarbons sorbed on active charcoal in tubes and CRM551 2, 4-DNPH derivatives in Acetonitrile). The limits of detection for seven days exposure for BTEX and terpenes were determined and found to be 0.1 μg/ m^3 for benzene, toluene, ethyl benzene, m,p-xylene and 0.2 μg/m^3 for o-xylene, a-pinene, 1.2 μg/m^3 for -TMB and D-limonene. The limits of detection for seven days exposure for carbonyls were determined and found to be 0.1 μg/m^3 for formaldehyde, acetaldehyde and acetone and 0.15 μg/m^3 for propionaldehyde and 0.3 μg/m^3 for hexanaldehyde.

For better data assessment air exchange rates measurements were also carried out using a tracer gas technique (NORTEST METHOD NT VVS 118). The temperature and relative humidity both indoors and outdoors were also recorded. Additionally, questionnaires were filled in as to provide valuable information regarding the sampled sites and activities that took place during the sampling period. More specifically, it consisted of three (3) sections. The first section gives general information about the sampling event (identification number, sampling period and the sampling team). The second sections concerns the building information and is divided in the background information (building type, address, contact details of the involved participant), building characteristics and other relative information (location, dimensions, number of floors, year of construction, indication of any renovation, type of equipment/furniture/appliances placed indoors, type and frequency of cleaning, type of heating). Finally, the third section contains data on the sampling sites (location, room's dimensions, room's materials, type (if any) of room's reconstruction/renovation, the presence of any mechanical ventilation, occupants' smoking habits, consumer products use and frequency). (Missia et al., 2010).

The sites

Table 1 summarizes the characteristics of the sites in

Table 1. Summarizes the characteristics of the sites in terms use, building type material present inside, and expected emission sources

Materials	Expected emitted priority compounds	CBD	Kanvili	Vittin	Kalpohin	Sagnerigu
Flooring						
Ceramic tiles	T,X	P,S1,S2	S2,P	H1,H2	S2,H1	P,S1
Sand cement screed	B,T,X	H2,P,S1	H1,H2	S2	S1	H1,H2
Porcelain	T,X	S1,P	H3	H2	H1	S2
Terrazzo	X,B	P,S2	H1	H4,H1	S1,H1	P,H4
Paints						
Plastic water based	F,B,A,T,X	S1,H3,H,4	P,S2	H3	H2,H4	S2,H3,H4
Acrylic	B,A,T,X	P,H4	H1,H3,H4	S1,H4	H3,H4	H1,H2,H3,
Gloss/Oil paint	B,T,F,A,	P1,S2	S1,H3,H2	P,S1	H1,P	P,H3,H4
Walls						
Wooden T&G	B,A,X	P,S2	S2,H4	H1,H3	P,H4,S2	H1,H2,H3,
Ceramic wall tiles	T,X	S2,H4,P	S2,H1	H1	H3	H1,H3
Sand cement rendering	X,T	P	H2	S2,H1	P	S1
Plastic T&G	B,F,T	P,H4	H4,H1	S2	H3,S1	H
Plaster of Paris rendering	B,T,F,A	S2	H	H	H2	H
Ceiling						
Plywood	F,A	S1,S2	H1,H3	H1,P	H	H
Plastic T&G	B,T,E,X	P	S2	S1	H4	H1,H2
Plaster of Paris	B,T,F,A	S2	P	H	H	H
Wooden T&G	F,A	P,S1	H3	H1	H	H1
Carpet						
Rugs	F,A	P	H1	H3	H	H
linoleum	F,A,T,X	S1	SI,H3	H4	H	H2
Furniture						
Hardwood	F,A	P	H,S1	H	H	H2
Particle board	F,A,X	P,S1	H3	S2,P	P	S1,H4
Plywood	F,A,T	P	H1,H3	S1	H	P
Varnishes	F,A,B	P,H3	S1	P	P	
Rugs/ leathers	T,A,X,	P,S2,H3	H	S2,H	H3,H2,H1	S1,S2

B -benzene, F -formaldehyde, X -xylenes, T-toluene, A -acetaldehyde.
P-public building, P2 -second public building tested, S -school/kindergarten,
S -school/kindergarten, H1- house 1, H2- house 2, H3- house 3, H4 -House 4.

terms of their use, the type of building material present inside, and the other expected emission sources.

Wood varnishing is a common practice used in buildings around the study area. Plaster walls and plastic water based paint are used practically everywhere. Plaster and plastic ceiling seems to be common too. Linoleum carpeting is also quite prevalent especially in the lower income parts. On the other hand, ceramic tiles, carpets and rugs commonly used and especially in public buildings and houses. Furthermore, cement mixtures and additives can also be found as both flooring and wall finishes. Additionally, furniture in all cases is constructed from similar wood based panels (covered particleboards or wood). Printing equipment is present in public buildings, as expected. In schools, the use of markers was also observed. In this table, one can see that the building materials existed in each measuring site can be identified as potential emission sources for all the priority pollutants.

Table 2 summarizes the indoor activities and ventilation types in each tested building according to the recorded data in the questionnaires. Due to the high diurnal temperatures, mechanical ventilation systems in the form of air conditioners and fans are commonly used in all the locations.

Additionally, smoking is not prohibited in public building (including schools), so there are reported cases of smoking in various buildings. Indoor activities, such as cleaning, cooking and use of disinfectants reported everywhere. Burning of incense and use of air fresheners are reported in houses. Finally, printers usually allocated in all public buildings. The sampled public buildings, and in all the locations, were occupied during the sampling period.

Table 2. Summarizes the indoor activities and ventilation types in each tested building.

Location	Public Building	School/kindergarten	House type 1	House type 2
CBD	City, Moderate traffic, Newly constructed building (2012). Human activity present. Natural ventilation and AC and fans. cleaning, printing	City, calm area, light traffic. New paint in 2013. Mechanical ventilation (fans) and AC. Cleaning, use of disinfectants and markers for teaching.	Suburban, calm area, light traffic. New paint (6) months ago. New furnishing in 2014. Natural ventilation and AC. Cleaning, cooking, wood burning, use of cosmetics/ disinfectants.	Suburban area, no traffic. No human activity for three (3) days. Natural ventilation and AC. Cleaning, use of disinfectants.
KANVILI	Suburban, light traffic. New paint, furnishing and flooring in 2013. Fans and AC Cleaning, printing	Suburban, light traffic, New paint in 2015. Natural ventilation. Cleaning and use of disinfectants	Suburban area, light traffic. Constructed in 2011. Natural ventilation and AC. Cooking, cleaning, wood burning, use of wood polishers	Suburban, light traffic. New paint, flooring and furnishing in 2009. Smoking. Natural ventilation and AC. Cooking, smoking, cleaning, use of air fresheners/deodorant
VITTIN	Urban area light traffic. Newly constructed (2015). Fans and AC. Cleaning, use of disinfectants and markers for classrooms	Suburban area, light traffic, New paint in 2014. Natural ventilation and fans. Cleaning and use of disinfectants	Suburban area, light traffic. Constructed in 2012. Natural ventilation and AC. Cooking, cleaning, wood burning, use of wood polishers	Suburban area, light traffic. New paint, flooring and furnishing in 2013. Smoking. Natural ventilation and AC. Cooking, smoking, cleaning, use of air fresheners/deodorants
KALPOHI-N	Urban, near heavy traffic. New furnishing in 2010. New painting in 2015. Natural ventilation. Cleaning, printers used.	Urban, near heavy traffic. Natural ventilation with fans and AC. Cleaning, cooking, use of disinfectants and markers.	Suburban, with mainly single family homes, near light traffic. Reconstruction and painting during 209-2015. Natural ventilation. Cooking, cleaning, wood burning, use of wood polishers, burn of incense and candles.	Suburban area with mainly Compound houses, near. Natural ventilation. Cooking, cleaning.
SAGNERI-GU	Suburban, light traffic. New painting, flooring and furnishing in 2013. Cleaning, use of disinfectants, air fresheners	Suburban, light traffic. New painting, flooring and furnishing in 2012. Natural ventilation. Cooking, cleaning, use of disinfectants/air fresheners/ markers.	Suburb with mainly bungalow type houses, no traffic. Fans and AC. Cooking, wood burning, cleaning, use of wood polishers/deodorants/air fresheners	Urban, near light traffic. New painting, flooring and furnishing in 2014. No human Activity, cleaning, use of wood polishers/air fresheners

Source: Missia et al., 2010

Ventilation, humidity and temperature

Table 3 presents the range of the indoor temperature, relative humidity and air exchange rate, as were recorded during the field studies. It can be observed that ventilation rates show diversity and this trend follows for humidity, as well. Temperature ranges from 16^{o}C to 34^{o}C in dry and 18^{o} C to 32^{o}C in rainy season. The air exchange rates were not expected to be the same in the two seasons. The air exchange rates in public buildings with natural ventilation ranged between 0.39 to 1.34/h close to the range for houses. However, air exchange rates for natural ventilation in schools may be much lower probably due to the nature of openings. Figure 1a, b and c shows the indoor air concentration during rainy and dry seasons in various locations. As it can be observed, with the exception of school buildings, ventilation rates are higher during rainy season especially in public buildings.

RESULTS AND DISCUSSION

VOCs concentration and emissions

Figure 2 shows the indoor concentrations ranges of the measured compounds in all sites. The data show a considerable diversity due to the different indoor emission sources, ventilation rates, building type, and outdoor environment. Most of average concentrations remain below 50μg/m^{3}. Elevated concentrations have been observed in houses and in public buildings. Houses seem to have the maximum concentrations for toluene (163.5μgm/3), m, p-xylenes (177.4μgm/3), d-limonene (159.4μgm/3), acetone (308.8μgm/3) and hexanaldehyde (113.3μgm/3). On the other hand, it appears that schools have the lowest average concentrations for all measured compounds.

Formaldehyde average concentrations are almost equal in each one of the three types of

Table 3. Presents the range of the indoor temperature, relative humidity and air exchange rate

Building type	**Air exchange (per hour)**		**Relative humidity (%)**		**Temperature (^{o}C)**	
	Dry season	**Rainy season**	**Dry season**	**Rainy season**	**Dry season**	**Rainy season**
Public buildings	0.18-1.35	0.31-0.82	26-65	27-58	16-38	18-27
Schools	0.35-0.70	0.5-1.5	25-60	29-70	15-40	14-29
Houses	0.4-1.45	0.3-1.45	23-62	32-75	16-34	17-28
Air exchange rates (per hour)	Public buildings		Schools		Houses	
Mechanical ventilation	0.28-1.65		0.35-1.45		0.3-1.25	
Natural ventilation	0.45-1.25		0.45-1.30		0.6-1.0	

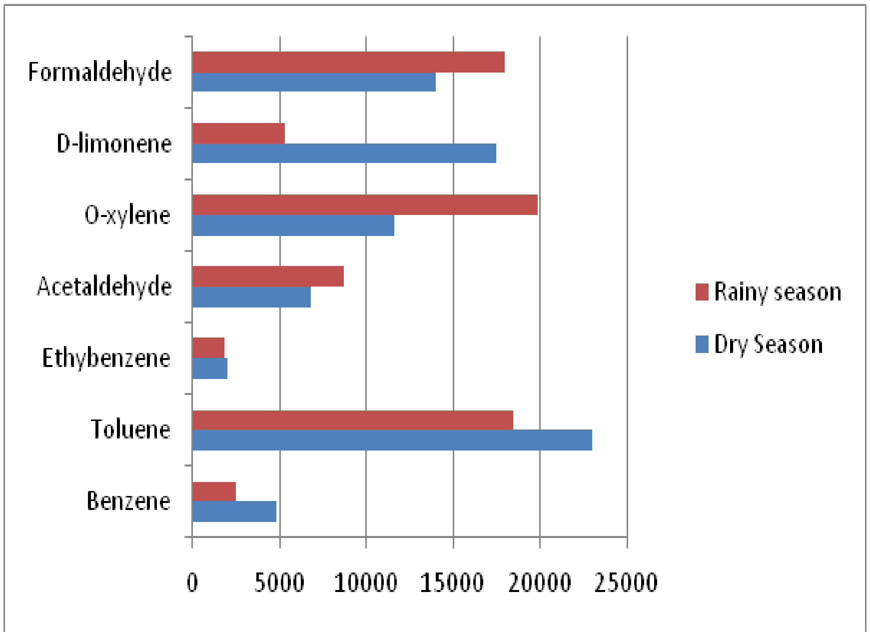

Figure 1a. Shows the indoor air concentration during rainy and dry seasons in School buildings

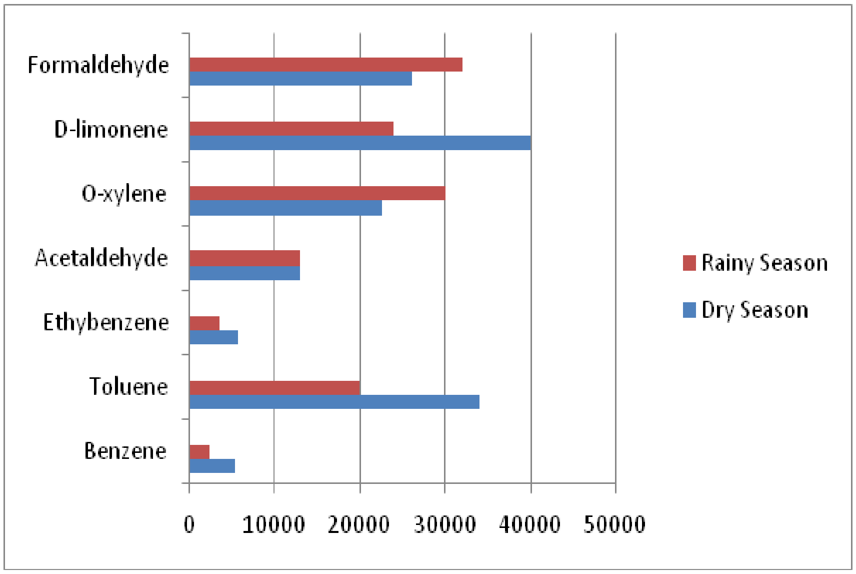

Figure 1b. Shows the indoor air concentration during rainy and dry seasons in Houses

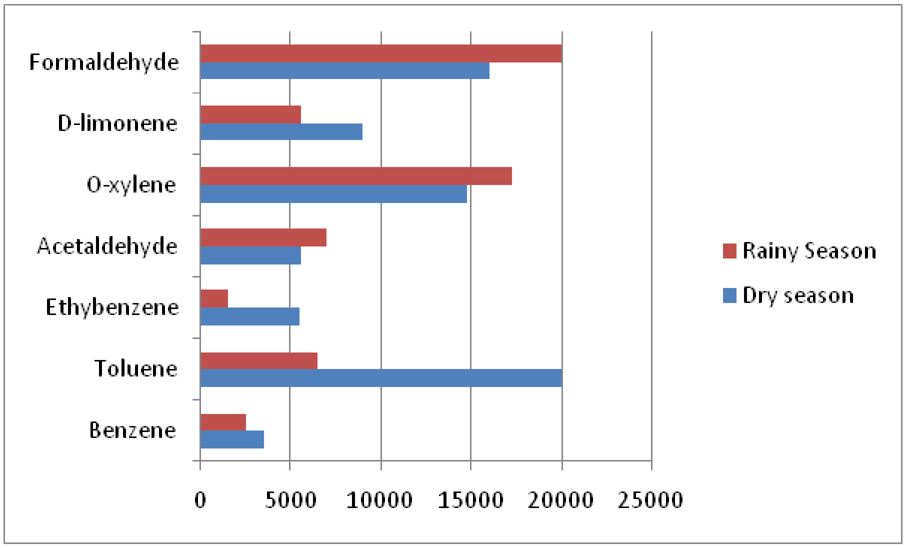

Figure 1c. Shows the indoor air concentration during rainy and dry seasons in Public buildings

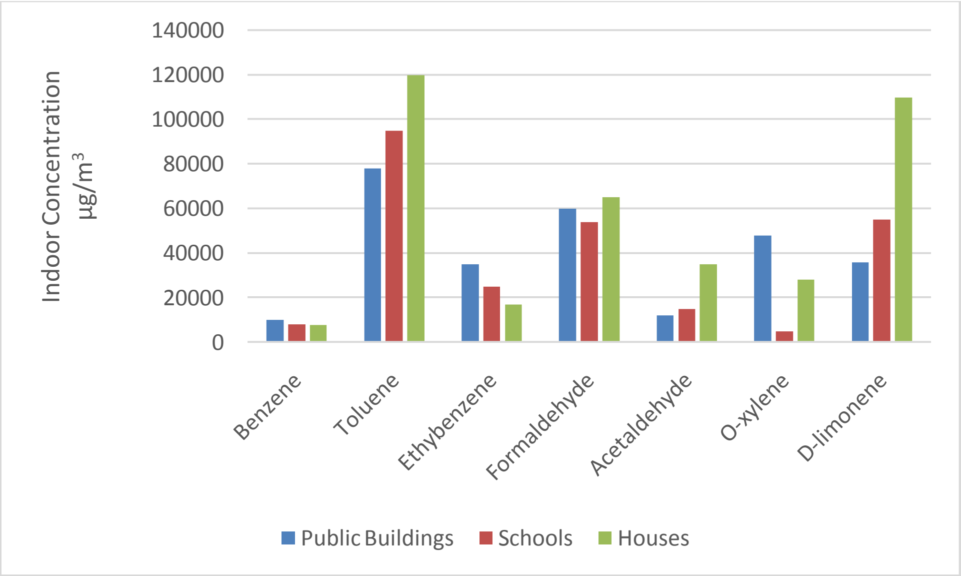

Figure 2. Shows the indoor concentrations ranges of the measured compounds in all sites.

buildings. Indoor air pollutants such as benzene, formaldehyde and acetaldehyde show indoor concentrations ranges of 0.1- 10.2, 5.8-62.6 and 0.7-41.6 µgm/3 respectively. The levels of formaldehyde remain below the WHO guideline of 100 µgm/3 for 30-minute average exposure (WHO, 2000). It is noticed that the levels of formaldehyde concentrations are comparable with the ones reported in the AIRMEX study (Kotzias et al., 2009).

The maximum concentration observed in Public buildings around the CBD (62.6µg/m3) are greater than the values reported in Paris dwellings (Clarisse et al., 2003) and lower than the most recently obtained values for France (OQAI, 2006). Benzene concentrations were lower than the average annual limit of 5µg/m3, which was set by EU for outdoor air (EC, 2000), except for some few houses in Kalpohin. The location of these houses is a suburban area near heavy traffic (500 m) and smoking activities were taken place indoors. Charcoal and fuel wood fires as well as gas appliances for cooking in operation, probably have led to the observed elevated concentration levels. The acetaldehyde and hexanaldehyde levels in most of the houses were similar to those found for in indoor environments in Strasbourg (Marchland et al., 2006). Acetone levels in the same public buildings seem to be slightly higher than those found in hospitals in China (Huixiog et al., 2006).

Figure 3 gives the chemical classes that contribute mainly to indoor concentration levels. The chemical classes that have the biggest contribution to the total measured VOC indoors vary from building to building and also among locations. For example, around the CBD, the public building that was tested, presented values of total measured VOC of the order of 276.6μgm/3. 46% corresponds to aromatic hydrocarbons and 45% to carbonyls and ketones. On the other hand, the tests that were carried out in the school showed 122.1 set by EU for outdoor air (EC, 2000), except for some houses in Kalpohin. The location of this house is a suburban area near heavy traffic (500 m) and smoking activities take place indoors. Fuel wood, charcoal gas appliances for cooking in operation; probably have led to the observed elevated concentration levels.

The acetaldehyde and hexanaldehyde levels in most of the houses were similar to those found for in indoor environments in Strasbourg (Marchland et al., 2006). Acetone levels in CBD public building seems to be slightly higher than those found in hospitals in China (Huixiog et al., 2006). m/3 of total measured VOC and in contrast to the previous example exhibit 60% of carbonyls and ketones and 33% of aromatic hydrocarbons.

Table 4 presents the derived Indoor to Outdoor concentration ratios (I/O) for the measured substances. The I/O ratios which have found >10 are indicated with bold. For most VOCs there is a clear indication of strong indoor sources. For example, for formaldehyde we can observe values up to 16.4 whereas for acetaldehyde this value raises up to 31. Formaldehyde is expected to come from flooring and/or furnishing (Kelly et al., 1999). On the other hand, acetaldehyde indoor emissions are mainly associated with human activities rather than building materials (Marchland et al., 2006). The maximum I/O ratio values for many substances seem to be associated with the presence of new building materials inside or with the use of certain consumer products during sampling period (i.e. nail polishes, painting and printing material in schools etc.). An example of this situation is reported in a school hostel near Sagnerigu where acetone levels were elevated due to the extensive use of nail polishing (as recorded in the questionnaire). Benzene ratios do not seem to be substantially different than one, indicating no or weak indoor sources. The ban in the use of benzene which was set in 1978 by US consumer Product Safety Commission (CPSC) and the identification of benzene as a known human carcinogen by IARC (1982), have led to the elimination of its use as an ingredient in consumer products and materials, and currently is not intentionally added at all (Weschler, 2009). Toluene indoor levels have a clear connection with carpet emissions; however furnishing could be also a source (Alevantis, 2003; Katsoyiannis et al., 2008). Furthermore, xylenes high indoor levels could be explained by considering their primary indoor source which is plaster on walls and secondly the use of adhesives (Katsoyiannis et al., 2008; Horn et al., 2007).

Figure 1a and b presents the comparison between dry and rainy seasons indoor concentration levels according to each building type. Indoor concentrations of all substances were higher during the hot dry period (March-April) of the dry season except for formaldehyde, acetaldehyde and hexanaldehyde. This observation could be associated with the limited ventilation during this period and/or other processes that may occur indoors. In the case of carbonyls, the seasonality may depend on living conditions which are different between occupants of buildings. On the other hand aromatics and terpenes seem to be reduced substantially during the rainy season, especially in public buildings. For xylenes in schools, seasonality does not play any key role, no significant differences in concentration levels have been observed. A number of other studies have also described the same behavior for indoor VOCs (Schlink et al., 2004; Schneider et al., 2001; Ilgen et al., 2001; Shields et al., 1996; Gilli et al., 1990).

Although there are numerous studies in which VOCs Indoor concentrations were assessed in newly or renovated buildings, little is known concerning the behavior of these compounds in the same buildings after a certain period (Jarnstrom et al., 2006). Figure 4 demonstrates the building construction time effect in a newly constructed building. This building was selected because of its age and the fact that it was not occupied during the first study (2 months after completion). The second study was carried out after 18 months of construction. It is observed that the concentrations of aromatics are elevated during the first study, indicating that probably came from the building materials, as no other human activity occurred. In the contrary, carbonyls have shown an increasing trend, between the two measurements, probably due to the existence of other indoor sources apart from building materials contribution.

Figure 5 shows the contribution of building material emissions to indoor air quality, as they were derived by the FLEC on site measurements. In Figure 5 the y- axis parameter is define as

$$\frac{1}{Cin}\frac{EA}{\lambda}100 \qquad \text{(Missia et al., 2010).}$$

Which is the measure of the excess concentration due to the emission rate E (μgm/^{2} /h) of the compound under consideration;

A is the area of the tested material (m^2);

1 is the air exchange rate (h/1);

V is the room volume (m^3);

Cin is the room measured concentration for the specific compound.

It can be observed that the building material emissions contribution in many cases was significant and have reach 40-50%. It is worth mentioning that benzene emissions were lower than 0.5μgm2h/1 and

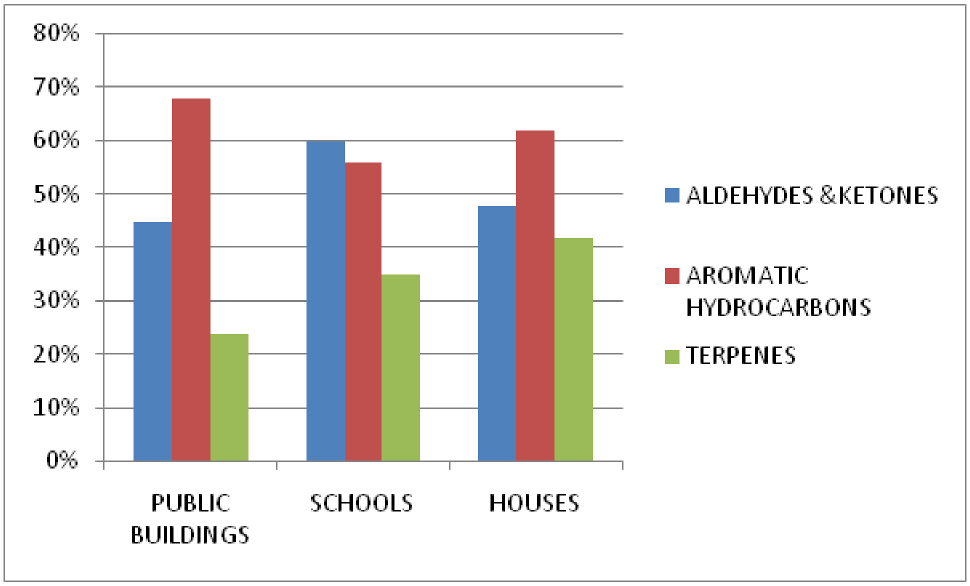

Figure 3. Gives the chemical classes that contribute mainly to indoor concentration levels

Table 4. Indoor to Outdoor ratios for all measured substances

	Public Buildings	Schools	Houses
Benzene	0.14-1.32	1.23-4.2	0.75-3.0
Toluene	0.98-5.0	1.4-**26.0**	1.5-**14.0**
Ethylbenzene	0.2-9.1	1.04-4.1	1.3-26
Formaldehyde	0.9-**12.0**	4.3-12	4.5-16
Acetaldehyde	0.85-8.7	2.6-16.2	2.5-34
O-xylene	0.8-8.5	1.0-13.1	1.35-15
D-limonene	2.5-**44**	1.5-**47.6**	1.5-**56.0**

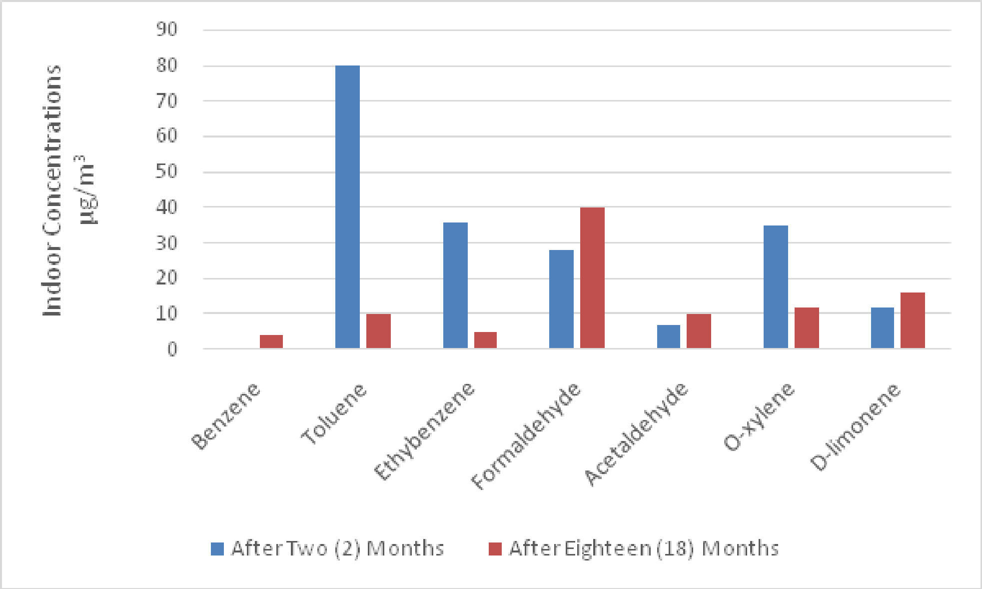

Figure 4. Demonstrates the building construction time effect in a newly constructed building.

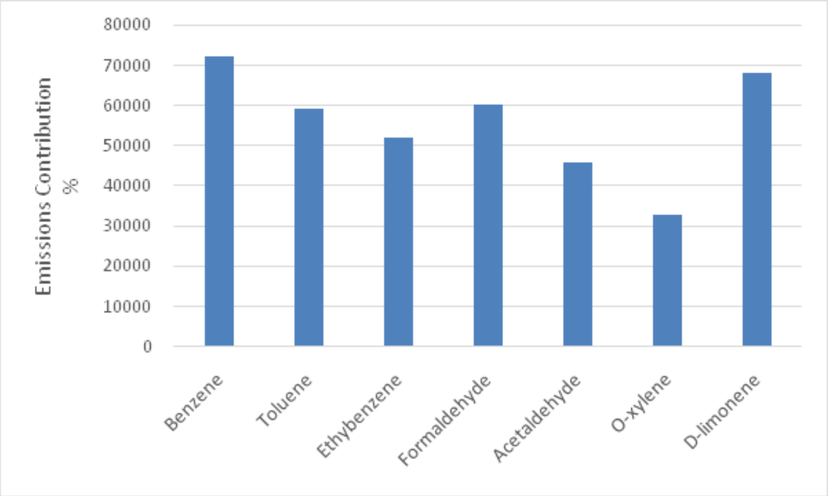

Figure 5. Emission contribution of different chemicals from all building types

taking into account the indoor levels, no significant contribution came from building materials.

CONCLUSIONS

From the above discussion the following conclusions can be drawn:

1. The frequently used materials in buildings selected for the present study were found to be water based paint, plaster and particleboards.
2. The concentrations of VOCs show a considerable variation due to the different indoor emission sources and outdoor environment concentrations.
3. The chemical classes that contribute mainly to the indoor air concentrations are carbonyls and ketones followed by aromatics.
4. Winter indoor concentrations are, in general, higher than those reported in summer period probably due to the different air ventilation regimes in the buildings. However, the findings for carbonyls need further investigation.
5. The indoor excess concentrations of formaldehyde, acetaldehyde, acetone and d- limonene, indicate relatively significant indoor emission sources of these substances in all buildings.
6. The emission sources in some buildings were originately from building material.
7. Present data indicate that emissions of hydrocarbons such as BTEX and terpenes from building materials could be reduce over time. However, thisneed further investigation.

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How to cite this article: Abdul-Manan D (2016). Indoor exposure from building materials: A field study of Tamale, Northern Ghana. Int. J. Environ. Sci. Toxic. Res. Vol. 4(3):44-53