Advances in Environmental Research, Vol. 1, No. 4 (2012) 277-288 277
DOI: http://dx.doi.org/10.12989/aer.2012.1.4.277

Indoor exposure to hazardous air pollutants and volatile organic compounds in low-income houses in Lagos, Nigeria

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(Received October 15, 2012, Revised November 22, 2012, Accepted December 3, 2012)

Abstract. This study investigated exposure to air pollutants in rooms in low-income houses at Shomolu (R1), Mafoluku (R2) and Mushin (R3) in Lagos state. The concentrations of most measured exceeded limits of Illinois Department of Public Health (IDPH) for indoor air quality. Air quality index (AQI) in rooms studied was unhealthy for sensitive people in terms of CO, unhealthy in terms of SO_2 and very unhealthy in terms of NO_2 while moderate air quality was obtained in terms of PM_{10} in most rooms. High concentrations of carbontetrachloride, formaldehyde and xylene measured could have been responsible for some of the health complaints of the occupants. Factor analysis shows that cooking with kerosene, use of gasoline generator and insecticide were the major contributors to indoor air pollution in these rooms. Therefore, there is need to urgently tackle poverty as all affected by these pollutants were poor who live in substandard houses without kitchens.

Keywords: air quality index; indoor air pollution; hazard quotient; cancer risk; factor analysis

1. Introduction

Exposure to air pollutants has been reported to cause health effects, genetic structure alterations, weaken immune system, asthma, headache, dry eyes, nasal congestion, nausea, and fatigue depending on the type of pollutants, amount of pollutants, frequency of exposure and associated toxicity of specific pollutants (Moschandreas and Sofuoglu 2004, Padhi *et al.* 2009, Sukhsohale *et al.* 2012). Indoor is one of main exposure routes to hazardous pollutants which can pose worse health effects than outdoor air pollution due to the substantially longer time spent indoors where dispersal of pollutants may be poor owing to lack of cross ventilation (Aerias 2005, IVHHN 2005, Ruiz *et al.* 2010). Indoor air pollutants usually include nitrogen oxides (NOx), sulphur dioxide (SO_2), carbon oxides (CO and CO_2), volatile organic compounds (VOCs), particulates and radioactive radon (McKone *et al.* 2009). Exposure to CO has been reported to impair the oxygen

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binding capacity of hemoglobin. It has also been linked with dizziness, breathlessness, fatigue, coma and death (IVHHN 2005, Mejia *et al.* 2011). Indoor NO_2 exposure has been shown to enhance asthmatic reactions (Neupane *et al.* 2010). SO_2 has been reported to cause broncho-constriction in healthy adults and adults with asthma. Particulate matters (PM) have been associated with increased respiratory symptoms and production of an inflammatory response on exposure to human lungs (Mejia *et al.* 2011). Exposure to VOCs has been reported to induce a wide range of acute and chronic health effects, such as sensory irritation, nervous system impairment, asthma and cancer. Many VOCs are known to be toxic, carcinogenic and mutagenic (Zhou *et al.* 2011). Benzene, formaldehyde and carbontetrachloride have been shown to damage liver, kidney, lung and intestine and DNA (Maruo *et al.* 2010).

Poverty has emerged as a significant predictor of health in Nigeria. Poor families live in poorly ventilated rooms in slums and squatter settlements with worst environmental conditions and they are vulnerable to ecological disasters such as flooding (Mengersen *et al.* 2011, Olaitan 2008). They majorly depend on kerosene for cooking, candles, generators for light and above all, lack access to basic infrastructural facilities like toilets which make their liquid waste disposal a nightmare (Clark *et al.* 2009). Arising from these realities and the lack of regulations and standards governing indoor air pollution, this study was carried to measure the concentrations of air pollutants in rooms in low-cost houses of Lagos state.

2. Materials and methods

2.1 Study area

Lagos seems to be the most populated state in Nigeria with a population estimate of 12 million people and a population density of 20,000 persons/sq km (Mabogunje 2002). The poverty level in Lagos is high and her government estimated that 51% men and 54% women residents in Lagos live below poverty line. Most of the people who live in slums like Ajegunle, Makoko, Oshodi, Shomolu and Mushin are usually low-income earners. High occupancy ratio and lack of access to basic housing facilities like kitchen and toilet characterize these houses (Olaitan 2008).

Fig. 1 A map showing the sampling location

Three locations in the metropolitan city of Lagos state were chosen: Shomolu, Mushin and Mafoluku. Five rooms in each location were chosen as representatives. These rooms are represented by *Rxy* where (*x*) represents location and (*y*) represents room respectively. Fig. 1 shows the sampling location and Table 1 gives description of these locations. The general characteristics of the rooms in the three locations include: all rooms studied are single rooms in the house with multiple rooms facing one another; generally non-spacious with high occupancy ratio of an average of four per room except at Mafoluku where higher occupancy ratio of average of 5 was recorded. Inhabitants are majorly self-employed and spend an average of nine hours per day in their rooms. They virtually depend on kerosene stoves for cooking mostly twice a day (morning and evening). Cooking is often done inside the room or in front of their rooms because kitchen was non- existing or overcrowded. They mostly depend on gasoline generators for electricity which are usually used in the evening for average of four hours per day and are placed beside the window or in front of their rooms. Due to vulnerability of these areas to flooding and lack of drainage system, they use insecticide to ward off insects. Most of the houses in these areas only have pit latrines.

2.2 Sampling

The study was to assess indoor exposure to hazardous pollutants in low-income rooms and was carried out in some selected rooms at the three locations between 7-8 pm in the evening and from

Table 1 Description of locations

Location	GPS	Coordinates	Number of occupants
	Latitude (N)	Longitude (E)	
Shomolu			
R1.1	06°32’34.16	03°22’49.20	4
R1.2	06 °32’33.50	03°22’47.10	5
R1.3	06°32’38.06	03°22’48.06	4
R1.4	06°32’36.33	03°22’51.00	3
R1.5	06°32’33.24	03°22’49..25	5
Mafoluku			
R2.1	06°33’09.47	03°20’05.80	5
R2.2	06°33’09.70	03°20’07.40	5
R2.3	06°33’08.23	03°20’03.21	4
R2.4	06°33’05.34	03°20’05.12	7
R2.5	06°33’13.82	03°20’09.62	4
Mushin			
R3.1	06°31’58.86	03°20’47.01	5
R3.2	06°31’52.71	03°20’40.53	5
R3.3	06°31’51.12	03°20’49.66	3
R3.4	06°31’23.81	03°20’51.36	6
R3.5	06°31’49.09	03°20’26.56	4

Table 2 Air quality index for criteria pollutants (USEPA 2000)

AQI category	AQI rating	PM_{10} (μgm^{-3})	NO_2 (ppm)	SO_2 (ppm)	CO (ppm)
Good (0-50)	A	0-54	0-0.053	0.00-0.034	0.0-4.4
Moderate (51-100)	B	55-154	0.054-0.1	0.035-144	4.5-9.4
Unhealthy for sensitive group (101-150)	C	155-254	0.1-0.36	0.145- 0.224	9.5-12.4
Unhealthy (151-200)	D	255-354	0.36-0.64	0.225- 0.304	12.5-15.4
Very unhealthy (200-300)	E	355-424	0.65-1.24	0.305- 0.604	15.5-30.4
Hazardous	F	425-504	1.25-1.64	0.605-0.804	30.5-40.4

Friday to Sunday between January and March, 2012. The samplings were done with the occupants' permission and in the real life situations when all their daily activities such as cooking and use of generaor were being carried out.

2.3 Hazardous air pollutants

Multi Gas Detector MultiRAE IR, (Model No: PGM-54), China, was used to measure: carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic compounds (VOCs), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). Handheld aerosol monitor (Casella Microdust pro 880 nm), USA, was used to measure PM_{10} and noise was measured with Extech integrating sound level meter (Model No: 407780), China. H_2S was determined using BW Gas Alert micro 5PID (USA). Temperature and relative humidity were measured using Kestrel 4500 NV Weather Meter (USA). Each instrument was allowed to equilibrate for at least 2 minutes before readings were taken. The procedure described by (Olajire *et al.* 2011) was used for calibration to ascertain the quality performance of all instruments. All gases, total volatile organic compounds and noise were determined in-situ four times per hour at 15 minutes interval. The average of the four determinations gave the concentrations of each pollutant in the room. Air quality index using Eq. (1) was used to calculate the health implications of the criteria pollutants as proposed by United State Environmental Protection Agency (USEPA 2000).

$$I_p = \frac{I_{high} - I_{low}}{BP_{high} - BP_{low}}\left(C_p - BP_{low}\right) + I_{low} \tag{1}$$

where, I_p is the index value for pollutant, *P*; C_p is the truncated concentration of pollutant, *P*; BP_{low} and BP_{high} are the concentration breakpoints with their corresponding AQI values of I_{high} and I_{low}, respectively. The indexes for the pollutants; NO_2, PM_{10}, CO and SO_2, were obtained from Eq. (1) using their respective breakpoints and associated AQI values in Table 2.

Table 3 GC-FID conditions for VOC analysis

GC-FID conditions	
Column	CP-Sil 5CB, 25m x 012 μm, ID 0.32 μm
Oven	35°C (2min) to 80°C @ 5°C/min
Carrier	Ultra-pure hydrogen gas
Detector	FID, 300°C
Injector temperature	300°C

2.4 Volatile organic compounds and quality control procedures

The method of Bae *et al.* (2004) was used for VOC determination with slight modification. Volatile organic compounds were sampled into tube containing activated charcoal with P4LC sampler at rate of 1 L/min for 10 minutes. The charcoal was chemically desorbed with 2 ml carbondisulphide (CS_2) and the content was analyzed using Gas Chromatograph (Hewlett-Packard Model, 501, USA) equipped with a Flame Ionization Detector. The conditions of GC-FID are listed in Table 3. Duplicate samples were collected at all sampling times and blank samples were analyzed just as the samples. Standards of VOCs mixture containing all investigated constituents were prepared and calibration curves were plotted. Correlation coefficients of the calibration curves plotted show high significance and range between 0.9994 and 0.9998.

2.5 Statistical analysis

Data are expressed as mean ± standard deviation of 36 replicates. They were subjected to one-way ANOVA and factor analysis to evaluate significant contribution and sources of pollutants studied. SPSS 15 version was used for the statistical analysis and significant differences were tested at $p < 0.05$.

3. Results and discussion

3.1 Hazardous indoor air pollutants and their air quality indices

Table 4 presents the concentrations of indoor air pollutants measured in fifteen rooms at three locations for 36 days. The results obtained were compared with Illinois Department of Public Health (IDPH 2003) guidelines for indoor air quality (Table 4). The indices of health effects of these hazardous air pollutants evaluated from Eq. (1) are presented in Table 5. Concentrations of CO_2 ranged between 738 ppm at R1.1 to 1080 ppm at R2.4. Concentrations of CO_2 were generally higher in rooms at Mafoluku than rooms at other locations. The levels of CO_2 were lower than the maximum limit of 1000 ppm set by IDPH except at R1.4 where it was higher than 1000 ppm. CO_2 is used as an indicator of ventilation rate. Presence of high levels of CO_2 suggests lack of good ventilation. Significant correlations ($p < 0.05$) were obtained between CO_2 and CO (0.78), SO_2 (0.73), PM_{10} (0.88), ethylbenzene (0.86) and formaldehyde (0.66) suggesting that they could all be from the same sources.

CO levels were between 6.78 ppm at R1.3 and 15.07 ppm at R1.5. CO levels were higher in all locations except at R1.3, R2.2 and R3.2 than the limit of 9 ppm for 8 h and less than 35 ppm limit for 1 h set by IDPH. Air quality index in terms of CO shows moderate air quality in R1.3, R2.2

Table 4 Concentrations of air pollutants measured in study locations (n = 36)

Location	Pollutants								
	CO_2 (ppm)	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	H_2S (ppm)	PM_{10} ($\mu g/m^3$)	NOISE (dBA)	Relative humidity (%)	Temp (°C)
R1.1	738.67 ± 61.99^a	10.17 ± 1.47^a	0.51 ± 0.05^a	0.22 ± 0.01^a	0.12 ± 0.03^a	94.17 ± 8.71^a	64.46 ± 6.07^a	68.22 ± 4.31^a	29.73 ± 1.77^a
R1.2	861.93 ± 40.13^b	11.72 ± 0.24^a	0.34 ± 0.01^b	0.24 ± 0.02^a	0.08 ± 0.01^b	107.21 ± 3.07^a	61.92 ± 0.76^a	66.45 ± 7.28^a	29.98 ± 2.56^a
R1.3	782.15 ± 23.47^a	6.78 ± 0.02^b	0.47 ± 0.06^b	0.12 ± 0.01^b	0.11 ± 0.01^a	102.20 ± 6.56^a	89.36 ± 1.27^b	69.05 ± 2.17^a	28.20 ± 3.10^a
R1.4	892.17 ± 38.49^b	12.53 ± 1.56^a	1.02 ± 0.04^c	0.31 ± 0.07^c	nd	126.71 ± 9.14^b	83.61 ± 1.54^b	63.78 ± 1.92^a	28.62 ± 2.65^a
R1.5	904.23 ± 56.16^c	15.04 ± 0.08^c	0.82 ± 0.03^d	0.29 ± 0.02^c	0.06 ± 0.01^b	145.24 ± 12.59^c	91.76 ± 2.43^b	67.02 ± 4.11^a	28.47 ± 2.87^a
R2.1	928.67 ± 96.80^c	11.17 ± 1.47^a	0.65 ± 0.08^d	0.23 ± 0.06^a	0.08 ± 0.01^b	172.83 ± 14.36^d	78.78 ± 4.16^b	64.01 ± 5.05^a	30.08 ± 1.71^a
R2.2	972.14 ± 54.27^c	8.92 ± 0.12^a	0.92 ± 0.02^c	0.21 ± 0.03^a	0.09 ± 0.01^b	185.24 ± 11.67^d	77.91 ± 6.21^b	68.69 ± 4.07^a	28.85 ± 1.22^a
R2.3	810.67 ± 37.82^b	10.47 ± 0.24^a	0.58 ± 0.03^a	0.26 ± 0.01^a	0.10 ± 0.03^a	170.01 ± 10.02^d	82.24 ± 1.85^b	66.09 ± 0.14^a	30.57 ± 2.47^a
R2.4	1080.57 ± 89.81^d	12.15 ± 0.06^a	0.93 ± 0.07^c	0.31 ± 0.05^c	0.16 ± 0.04^c	141.87 ± 15.81^c	78.29 ± 3.04^b	66.52 ± 3.76^a	31.45 ± 1.68^a
R2.5	880.05 ± 73.19^b	9.42 ± 0.80^a	0.67 ± 0.01^a	0.28 ± 0.07^c	0.13 ± 0.01^c	179.15 ± 18.90^d	81.55 ± 6.18^b	69.23 ± 1.18^a	29.77 ± 4.58^a
R3.1	872.02 ± 51.92^b	10.33 ± 1.21^a	0.55 ± 0.15^a	0.27 ± 0.04^a	0.13 ± 0.04^c	140.01 ± 15.99^c	76.51 ± 6.41^a	65.84 ± 5.73^a	28.95 ± 1.03^a
R3.2	820.12 ± 21.19^b	8.23 ± 1.21^b	0.48 ± 0.04^a	0.30 ± 0.01^c	0.09 ± 0.03^b	145.58 ± 17.24^c	83.97 ± 5.18^b	68.59 ± 7.65^a	32.19 ± 4.82^b
R3.3	955.21 ± 60.11^c	11.42 ± 0.06^a	0.83 ± 0.01^d	0.19 ± 0.04^a	nd	165.17 ± 10.07^d	75.33 ± 6.22^a	67.07 ± 3.37^a	29.93 ± 1.87^a
R3.4	783.87 ± 16.03^a	12.18 ± 2.47^a	0.76 ± 0.05^d	0.23 ± 0.03^a	0.11 ± 0.02^a	122.38 ± 14.02^e	87.27 ± 1.34^b	69.11 ± 8.01^a	30.12 ± 5.47^a
R3.5	810.38 ± 24.46^b	9.87 ± 0.07^a	0.39 ± 0.06^a	0.29 ± 0.02^c	0.08 ± 0.01^b	154.56 ± 9.38^c	79.04 ± 3.49^b	68.99 ± 1.31^a	29.54 ± 2.65^a
IDPH Standard	1000	10-8h 35-1h	0.05	0.5	0.01	150		60	

Values with different superscripts along the same columns are significantly different ($p < 0.05$)
*Illinois department of public health (IDPH) 2003 - CO_2: carbon dioxide, CO: carbon monoxide, NO_2: nitrogen dioxide, SO_2: sulphurdioxide, H_2S: hydrogen sulphide, PM_{10}: particulate matters ≤ 10 μm, nd: not detected

and R3.2. Except at these three rooms, other rooms give unhealthy quality of air for sensitive. The main health effect could be headaches, nausea, dizziness, breathlessness, fatigue, coma and death (McKone *et al.* 2009) and might be why some occupants in the rooms studied complained of these symptoms. CO showed significant correlations ($p < 0.05$) with SO_2 (0.92), PM_{10} (0.81) and ethylbenzene (0.91).

NO_2 levels ranged from 0.39 ppm at R3.5 to 1.02 ppm at R1.4. Its levels were significantly higher in all locations compared with 0.05 ppm set by IDPH. In terms of NO_2, quality of air ranges from unhealthy for sensitive people to unhealthy and very unhealthy for inhabitants in all locations. Asthmatic attacks and allergies which were some of the complaints of the occupants could have resulted from exposure to NO_2 and may not be unconnected to housing structures due to poor ventilation, small apartment size, and frequent use of kerosene stove. (Brauer *et al.* 2002, Neupane *et al.* 2010). NO_2 significantly correlates ($p < 0.05$) with SO_2 (0.70) and PM_{10} (0.74).

SO_2 concentrations were in the range 0.12 ppm at R1.3 to 0.29 ppm at R3.5. SO_2 concentrations in all locations fall below the standard (0.5 ppm) of IDPH. Air quality in terms of SO_2 ranges from being moderate to unhealthy for sensitive people to unhealthy and very unhealthy for all inhabitants. Unhealthy and very unhealthy qualities of air caused by SO_2 suggest that the occupants in the rooms studied were exposed to high concentrations of the pollutant which could predispose them to respiratory infections, adverse health effects, broncho-constriction and mortality from long-time exposure as previously reported (Chauhan *et al.* 2003). SO_2 showed significant correlations ($p < 0.05$) with PM_{10} (0.70) and ethylbenzene (0.72).

H_2S levels range from not detected (nd) at R1.4 and R3.3 to 0.16 ppm at R2.4. The levels of H_2S where detected were majorly above the limit of 0.01 ppm set by IDPH.

PM_{10} was highest with 185.24 μg/m3 at R2.2 and lowest with 94.17 $\mu g/m^3$ at R1.1. Majority of rooms in location two (R2) have values higher than 150 μg/m3 set by IDPH. Except at (R2) and a room at location three which gave unhealthy air quality for sensitive people, others are moderate for PM_{10}. Some of the health complaints might be due to PM_{10} exposure as it has been reported to be associated with symptoms mentioned earlier (McKone *et al.* 2009). PM_{10} correlates significantly ($p < 0.05$) with ethylbenzene (0.85) and TVOC (0.73).

Noise levels range from 64.46 dB at R1.1 to 89.36 dB at R1.3. Noise levels in some of these rooms were high and could account for some aggressive behavior and psychological stress as observed by Osuntogun and Koku (2007).

Temperature range was between the highest 32.19°C at R3.2 and the lowest 28.20°C at R2.3. Relative humidity was highest at R3.4 with 69.11% and lowest at R1.4 with 63.78%. Temperature values in many of the rooms studied were above the room temperature of 27°C. Relative humidity at all locations was higher than 60% limit of IDPH. High temperature and relative humidity measured in this study could cause discomfort, dehydration and enhance the growth of molds, fungi and bacteria which could adversely affect occupants' health (Davis 2001).

3.2 Volatile organic compounds (VOC)

Table 6 presents the concentrations of benzene, toluene, ethylbenzene, xylene (mixed isomers), formaldehyde, carbontetrachloride and total volatile organic compounds (TVOC) in the sampled rooms. Data obtained in this study were compared with Hong Kong indoor air quality management group standards (HKIAQ 1999).

Concentrations of benzene ranged from 19.60 μgm^{-3} at R1.1 to 49.87 μgm^{-3} at R3.1. These values were higher than 16.1 μgm^{-3} limit of HKIAQ (1999). Benzene is a known carcinogen which can cause central nervous damage, leukemia, rapid heart rate, dizziness, unconsciousness and death (Leusch and Bartkow 2010, Zhang *et al.* 2012). Benzene significantly correlates ($p < 0.05$) with formaldehyde (0.70) and TVOC (0.72).

Concentrations of toluene ranged from 1.31 μgm^{-3} at R3.1 to 13.83 μgm^{-3} at R3.5. The values measured were all below the 1092 μgm^{-3} limit of HKIAQ (1999). The lower values do not exonerate toluene from causing hazards because is known to affect brain, kidney and nervous (Leusch and Bartkow 2010). Toluene showed significant correlations ($p < 0.05$) with carbontetrachloride (0.82) and averagely contributed to TVOC (0.65). Ethylbenzene was lowest at R2.1 with 8.42 μgm^{-3} and highest at R3.5 with 25.34 μgm^{-3}. These concentrations were lower than 1447 μgm^{-3} limit of HKIAQ (1999). Ethylbenzene has been investigated to cause enlargement of liver, kidney and irreversible damage to ears (Leusch and Bartkow 2010). Ethylbenzene averagely correlates with formaldehyde (0.67).

Xylene concentrations varied from 109.15 μgm^{-3} at R1.2 to 312.51 μgm^{-3} at R3.1. They were all lower than 1447 μgm^{-3} limit of HKIAQ (1999). Xylenes have been reported to affect nervous system and cause lack of muscle coordination, confusion, dizziness, irritation of eyes and respiratory tracts (Leusch and Bartkow 2010). Xylene had highest significant ($p < 0.05$) contribution to TVOC (0.97).

Formaldehyde concentrations were lowest at R3.3 with 42.57 μgm^{-3} and highest at R2.5 with 98.63 μgm^{-3}. Concentrations measured were all higher than 30 μgm^{-3} limit of HKIAQ (1999). Formaldehyde is a suspected carcinogen which affects the nervous system and brain (Zhang *et al.*

Table 5 Air quality indices of priority pollutants measured in this study

Location	Pollutants			
	AQI CO	AQI NO_2	AQI SO_2	AQI PM_{10}
		Shomolu		
R1.1	C	D	D	B
R1.2	C	C	D	B
R1.3	B	D	B	B
R1.4	D	E	E	B
R1.5	D	E	D	B
		Mafoluku		
R2.1	C	E	D	C
R2.2	B	E	D	C
R2.3	C	D	D	C
R2.4	C	E	E	B
R2.5	C	E	D	C
		Mushin		
R3.1	C	D	D	B
R3.2	B	D	D	B
R3.3	C	E	C	C
R3.4	C	E	D	B
R3.5	C	D	D	B

2012). Acute exposure to formaldehyde has been shown to cause irritation of the eyes and upper airways, bronchitis, chest pain, wheezing, coughing and long-term exposure to lower levels has been associated with an increased risk of developing respiratory illnesses (Maruo *et al.* 2010). Carbontetrachloride concentrations range from 101.32 μgm^{-3} at R1.5 to 189.92 μgm^{-3} at R3.2. Except at R1.5, other concentrations of carbontetrachloride were higher than 103 μgm^{-3} limit of HKIAQ (1999). Carbontetrachloride has been reported to damage liver, kidney, lung and intestine (Zhang *et al.* 2012).

Table 6 Concentrations of volatile organic compounds measured in the study locations (n = 36)

Location	Volatile organic compounds (μgm^{-3})						
	Benzene	Toluene	Ethyl-benzene	Xylene*	Formal-dehyde	Carbontetra-chloride	TVOC
R1.1	19.60 ± 4.57	6.55 ± 0.13	12.05 ± 0.02	136.26 ± 38.07	54.85 ± 12.19	125.43 ± 7.32	602.41 ± 57.98
R1.2	26.10 ± 1.84	10.01 ± 0.43	17.59 ± 0.03	109.15 ± 16.19	89.58 ± 14.73	118.24 ± 23.55	708.25 ± 34.61
R1.3	11.69 ± 1.68	12.47 ± 1.27	11.27 ± 0.05	121.99 ± 27.11	59.97 ± 8.60	161.74 ± 14.87	654.19 ± 61.81
R1.4	18.16 ± 3.33	10.76 ± 0.59	15.67 ± 0.17	128.65 ± 35.21	67.26 ± 10.37	135.25 ± 16.02	816.50 ± 72.33
R1.5	16.67 ± 2.33	6.37 ± 0.18	21.48 ± 0.04	161.27 ± 37.45	72.56 ± 20.4	101.32 ± 19.72	732.12 ± 37.67
R2.1	27.80 ± 7.94	4.57 ± 0.42	8.42 ± 0.10	121.03 ± 20.08	93.47 ± 13.50	114.52 ± 7.67	795.40 ± 36.32
R2.2	46.26 ± 8.84	11.94 ± 2.32	10.13 ± 0.04	130.43 ± 32.07	83.13 ± 21.28	127.17 ± 14.57	806.39 ± 81.11
R2.3	15.82 ± 4.67	13.43 ± 0.33	9.52 ± 0.12	133.70 ± 41.40	86.75 ± 11.60	108.67 ± 13.57	756.14 ± 85.45
R2.4	7.06 ± 0.87	9.15 ± 0.38	7.83 ± 0.07	139.87 ± 21.33	76.48 ± 16.86	137.62 ± 10.06	823.72 ± 70.78
R2.5	12.17 ± 2.14	17.30 ± 2.46	16.03 ± 1.08	127.70 ± 31.30	98.63 ± 17.47	167.78 ± 25.67	716.16 ± 97.29
R3.1	49.87 ± 7.93	1.31 ± 0.03	17.16 ± 4.78	312.51 ± 52.03	65.03 ± 12.19	146.22 ± 43.16	878.63 ± 37.23
R3.2	21.33 ± 8.87	5.97 ± 0.48	21.24 ± 2.79	222.77 ± 44.04	73.04 ± 7.85	189.92 ± 11.57	921.50 ± 66.61
R3.3	37.66 ± 3.94	3.86 ± 0.56	13.41 ± 0.92	270.87 ± 30.03	42.57 ± 3.48	167.77 ± 19.61	792.18 ± 80.14
R3.4	31.65 ± 2.57	8.74 ± 1.73	9.07 ± 1.16	119.25 ± 22.16	59.01 ± 10.62	152.08 ± 8.76	816.46 ± 19.74
R3.5	43.25 ± 1.82	13.83 ± 1.07	25.34 ± 1.52	213.22 ± 41.06	61.27 ± 8.02	136.10 ± 20.95	834.28 ± 62.97
HKIAQ+	16.1	1092	1447	1447	30	103	

*Mixed isomer, + Honk Kong indoor air quality management group standards (HKIAQ 1999)

Table 7 Factor analysis of pollutants measured

Pollutant	Component			Communality
	*F*1	*F*2	*F*3	
CO_2	**0.95**	0.17	0.16	0.955
CO	**0.68**	**0.71**	0.23	0.999
NO_2	**0.75**	0.24	-0.47	0.859
SO_2	**0.73**	0.53	0.22	0.855
H_2S	-0.95	0.03	0.04	0.905
PM_{10}	**0.82**	0.46	-0.22	0.938
Benzene	0.08	0.17	**0.96**	0.954
Toluene	0.16	-0.98	-0.08	0.985
Ethylbenzene	**0.69**	0.58	0.28	0.866
Xylene	0.17	**0.83**	-0.53	0.991
Formaldehyde	0.48	-0.03	**0.78**	0.844
CCl_4	-0.29	**0.85**	-0.43	0.994
TVOC	**0.99**	-0.10	0.01	0.984
%Variance	51.49	23.98	17.64	
Cumulative%	51.49	75.62	93.10	

Extraction method: principal component analysis
Rotation method: Varimax with Kaiser normalization
Significant values are in bold
Only factors with eigenvalue ≥ 1shown
CO_2: carbondioxide, CO: carbonmonoxide, NO_2: nitrogendioxide, SO_2: sulphurdioxide, H_2S: hydrogen-suplhide, PM_{10}: particulate matters ≤ 10 μm, CCl_4: carbontetrachloride, TVOC: total volatile organic compounds

TVOC had its lowest concentration at R1.1 with 602.41 μgm^{-3} and highest at R3.2 with 921.50 μgm^{-3}. It is used as an indicator to predict the health effects of VOC; therefore, high value of TVOC suggests there could be health defects from exposure to VOC (Moschandreas and Sofuoglu 2004).

3.3 Factor analysis

To examine the possible sources and contributions of pollutants measured, factor analysis using principal component analysis (PCA) was conducted and the results are presented in Table 7. Three factors were extracted by PCA and they accounted for 93.10% of total variance (eigenvalue ≥ 1). *F*1 with variance 51.49% correlated with CO_2, CO, NO_2, PM_{10}, ethylbenzene and TVOC, was identified as a factor representing smokes from cooking using kerosene and gas, cigarette and generator (Hoddinott and Lee 2000, Padhi and Padhy 2008). *F*2 with variance 23.98% correlated with CO, xylene and CCl4, was identified as a factor representing insecticide usage, smokes and evaporation from gasoline powered-generator (Hoddinott and Lee 2000, Padhi and Padhy 2008, Zhou *et al.* 2011). *F*3, with variance 17.64% correlated with benzene and formaldehyde was identified as a factor representing paints, varnishes and solvents use (Hoddinott and Lee 2000, Raaschou-Nielsen *et al.* 2010, Zhou *et al.* 2011). The possible sources of these pollutants indicate that cooking inside their one-room apartment, use of generator beside the window and insecticide to ward off mosquitoes greatly contributed to the high concentrations of hazardous air pollutants and volatile organic compounds measured in these rooms.

4. Conclusions

Our study shows that the levels of hazardous air pollutants measured are capable of causing discomfort to the occupants of the studied rooms. Volatile organic compounds as revealed by cancer risks and hazard quotients are capable of inducing cancer from prolong exposure to indoor air in these rooms. Cooking with kerosene, usage of gasoline generator and insecticide are some of the possible sources of these pollutants. Generally, control measures should be taken to address the menace of indoor air pollution, especially at places where poor people live. This study thus recommends that with good electricity supply and use of insect-treated nets, indoor exposure to these hazardous pollutants will be greatly reduced. There is also the need for further research on indoor air pollution in Nigeria.

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