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Levels of hazardous air pollutants and volatile organic compounds in low-income houses in Lagos, Nigeria.

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Abstract: This study investigated the levels of hazardous air pollutants (HAP) and volatile organic compounds (VOCs) in rooms in low-cost houses at different locations: Shomolu (R1), Mafoluku (R2) and Mushin (R3) in Lagos state. The concentrations of most of the hazardous pollutants studied 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; indicating that air pollutants in these rooms are capable of causing various degrees of health hazards. Hazard quotients estimated from VOCs in these rooms were all higher than unity except for toluene, ethylbenzne and benzene in some rooms indicating that long exposure could lead to significant heath damage. All cancer risks of benzene, formaldehyde and carbontetrachloride estimated exceeded 1X 10^{-6}, suggesting that a life-long exposure may result into serious heath defects. Factor analysis shows that cooking with kerosene, usage of gasoline generator and insecticide were the major contributors to air pollution in these rooms. Occupants' exposure to these pollutants could be why most of them complained of wheezing, asthma attack, respiratory infections, eyes irritation, nausea and high hospital admission amongst others. 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 and Factor Analysis

INTRODUCTION

Exposure to indoor air pollutants has been reported to cause health defects, genetic structure alterations, weaken immune system, asthma, headache, dry eyes, nasal congestion, nausea, and fatigue depending on the type of pollutants, amount of the pollutants exposed to, duration and frequency of exposure, and associated toxicity of the specific pollutant (Moschandreas and Sofuoglu, 2004, Clark *et al.*, 2009, Padhi *et al.*., 2009, Raaschou-Nielsen *et al.*, 2010, Sherman and Walker, 2010, Sukhsohale *et al.*., 2012). Indoor is one of main exposure routes to hazardous pollutants which can pose many hundreds of times greater exposure 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 and biomass burning (Aerias, 2005, IVHHN 2005, Ruiz *et al.*., 2010). Studies have shown that most chemical substances which people are exposed to everyday constitute an additional risk factor in the development of several pathologies (Bruno *et al.*, 2008, Taneja *et al.*, 2008). Indoor air pollution occur from a result of complex interactions between the structure, building systems, indoor source strength, removal and deposition rate within the structure, indoor mixing and chemical reactions, furnishings, the outdoor environment, and the practices and the behaviours of the inhabitants (Moschandreas and Sofuglu, 2004, Taneja *et al.*., 2008). 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). CO has been reported to impair the oxygen binding capacity of hemoglobin which can lead to headaches, nausea, dizziness, breathlessness, and fatigue, and with high exposures can lead to coma and death (IVHHN 2005, Curtis *et al.*., 2008, Mejia *et al.*., 2011). Indoor NO_2 exposure has been shown to enhance asthmatic reactions due to inhaled allergens and can cause lung cancer. 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 (Mark *et al.*., 2002, Binod *et al.*., 2010, Mejia *et al.*., 2011, Kohli *et al.*, 2011). Volatile Organic Compounds (VOCs) are common air pollutants, and exposure to VOCs can 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 and considered to be carcinogenic, mutagenic, or teratogenic (Khan and Ghoshal, 2000, Son, *et al.*, 2003, Rager *et al.*, 2011, Zhou *et al.*, 2011). Benzene has been reported to induce DNA oxidation while carbon tetrachloride has been shown to damage liver, kidney, lung and intestine. Acute exposure to formaldehyde has been shown to cause irritation of the eyes and upper airways, and long-term exposure to lower levels has been associated with an increased risk of developing respiratory illnesses (Karthikeyan *et al.*, 2006, Edewor *et al.*, 2007, Maruo *et al.*, 2010).

Poverty has emerged as a significant predictor of health outcomes 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. Despite that most of the houses in Lagos are substandard, they are still not affordable by poor and choicelessly they settle for rooms in unbuildable terrain. (Olukayode, 2005, Lawanson, 2008, Mergessen *et al.*, 2011). They majorly depend on kerosene for cooking, candles, generators for light and above all, lack access to basic infrastructural facilities like toilets which

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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 and outright violation of standard settings for room construction, this study was carried to measure the concentrations of hazardous air pollutants and volatile organic compounds in rooms in low-cost houses of Lagos state vis-a-vis possible health outcomes.

Materials and Methods

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. Most of the houses they have high occupancy ratio and lack access to basic housing facilities like kitchen and toilet (Lawanson, 2008).

Three locations in the metropolitan city of Lagos state were chosen: Shomolu, Mushin and Mafoluku. These locations were chosen as typical rooms where an average Lagosian lives are found. They have been investigated to be peopled predominatly by urban poor (Lawanson, 2008). Five rooms in each location were randomly sampled and analyzed as representatives. These rooms are represented by Rxy where (x) represents location and (y) represents room respectively. Figures 1a and b show one of the houses studied, figure 2 shows the sampling location and table 1 gives description of these locations.

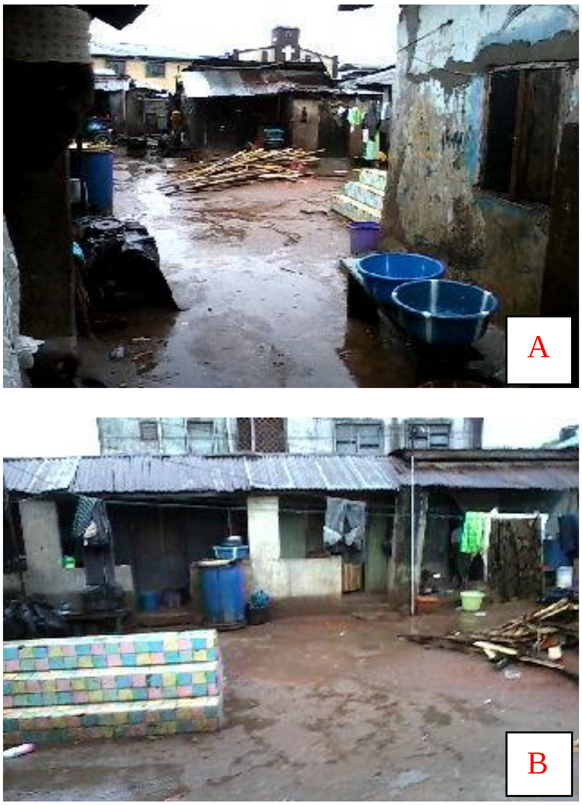

Figure.1: A; side view and B; front view of one the houses studied.

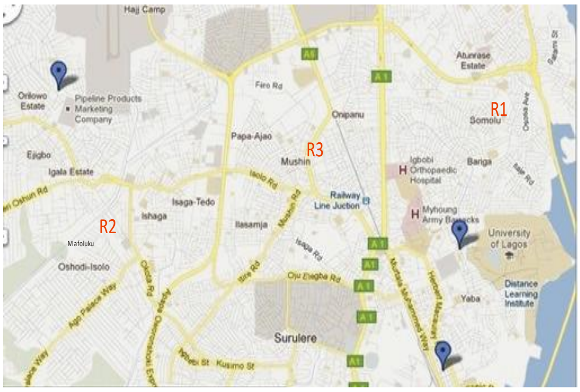

Figure 2: A map showing the sampling location

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; they are 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 and growths of algae were noticed on outside walls. Inhabitants are majorly self-employed and spend an average of nine (9) hours per day in their rooms. They virtually depend on kerosene stoves for cooking which they do 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. Mushin is the most volatile location out of the three where thugs smoke Indian without any hindrance. Only insignificant numbers of occupants smoke in all locations.

Table 1: Description of locations

Location	GPS Coordinates		N0. of Occupants
	Latitude (°N)	Longitude (°E)	
SHOMOLU			
R1.1	06.323350	03.224710	4
R1.2	06.323350	03.224710	5
R1.3	06.323806	03.224806	4
R1.4	06.323633	03.225100	3
R1.5	06.323324	03.224925	5
MAFOLUKU			
R2.1	06.330947	03.200580	5
R2.2	06.330970	03.200740	5
R2.3	06.330823	03.200321	4
R2.4	06.330534	03.200512	7
R2.5	06.331382	03.200962	4
MUSHIN			
R3.1	06.315886	03.204701	5
R3.2	06.315271	03.204053	5
R3.3	06.315112	03.204966	3
R3.4	06.312381	03.205136	6
R3.5	06.314909	03.202656	4

Sampling: The study was carried out in some selected rooms at the three locations between 7-8pm in the evening and from 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 generator were being carried out.

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 880nm), 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 4500NV Weather Meter (USA). Each instrument was allowed to equilibrate for at least 2minutes 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 15minutes interval. The average of the four determinations gave the concentrations of each pollutant in the room. Air quality index using equation 1 was used to calculate the health implications of the criteria pollutants as proposed by United State Environmental Protection Agency (USEPA), 2000. Table 2 shows the air quality index category

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

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 that is (and) C_p with their corresponding AQI values of I_{high} and I_{low} respectively.

Table 2: Air quality index for criteria pollutants

AQI CATEGORY	AQI rating	PM_{10} (μgm^{-3})	NO_2 (ppm)	SO_2 (ppm)	CO(ppm)
Good (0-50)	A	0-54	-	0.00-0.034	0.0-4.4
Moderate (51-100)	B	55-154	-	0.035-144	4.5-9.4
Unhealthy for sensitive group (101-150)	C	155-254	-	0.145-0.224	9.5-12.4
Unhealthy (151-200)	D	255-354	-	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

USEPA, 2000

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 the rate of 1L/min for 10min. The charcoal was chemically desorbed with 2ml carbondisulphide (CS_2) and the content was analyzed using Gas Chromatograph (Hewlett-Packard Model, 501, (USA) GC) equipped with a Flame Ionization Detector. The conditions of GC-FID are listed in table 2. Duplicate samples were collected at all sampling times and blank samples were and analyzed just as the samples. Internal standards of VOC s 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.

Cancer and non-carcinogenic hazard ratio:

VOCs are of high significance as they are directly related to the health of human beings in day-to-day life. The VOCs measured such as benzene, formaldehyde and carbontetrachloride have been classified as carcinogens (Srivastava *et al.*, 2000, Zhang *et al.*, 2012). Others have been identified to cause other health defects apart from cancer. In order to evaluate the potential hazards of VOCs on the health of occupants in these rooms through inhalation, this study used unit risk data from Nation-scale Air Toxics Assessment (NATA) which has recently emerged an important tool for estimating exposure concentrations and health risks associated with the inhalation of hazardous air pollutants and as provided by USEPA, 1999 (Tam and Neumann, 2004, Chakraborty, 2009, Chakraborty, 2012). Cancer risk estimates in the NATA derived using inhalation unit risk (UR) factors (table 4), is a measure of the carcinogenic potency for each pollutant. Cancer risk is calculated using equation 2.

$$Cancer\ risk = VOC\ (\mu g/m^3)\ X\ \text{Unit risk}\ (\mu g/m^3)^{-1}$$

Non-cancer health risks are derived on the basis of the inhalation reference concentration (RfC) for each pollutant or reference exposure level (REL) (table 4). To estimate respiratory risk, a hazard quotient for each air pollutant known to affect the respiratory system is calculated using equation 3.

$$Hazard\ ratio = VOC\ (\mu g/m^3)/\ RfC, REL \qquad 3$$

Table 3: GC-FID conditions for VOC analysis

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

Table 4: Reference concentrations, reference exposure levels and unit risks of volatile organic compounds studied.

Chemical	RfC, REL ($\mu g/m^3$)	Unit risk ($\mu g/m^3$)$^{-1}$
Benzene	30	7.8×10^{-6}
Carbontetrachloride	40	4.5×10^{-5}
Formaldehyde	3	1.3×10^{-5}
Ethylbenzene	1000	-
Toluene	300	
Xylene	100	

Statistical analysis:

Data are expressed as mean ± standard deviation of 36 replicates. Data were subjected to factor analysis to evaluate source and contribution of pollutants studied.

RESULTS AND DISCUSSION

Hazardous indoor air pollutants and their air quality indices:

Table 5 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 5). The indices of health effects of these hazardous air pollutants evaluated from equation 1 using air quality index (AQI) of USEPA, 2000 (Table 2) are presented in table 6. Concentrations of CO_2 ranged between 738ppm at R1.1 to 1080ppm 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 1000ppm set by IDPH except at R1.4 where it was higher than 1000ppm. CO_2 is used as an indicator of ventilation rate. Presence of high levels of CO_2 suggests lack of good ventilation. High Concentrations of CO_2 measured in this study could be the why some occupants complained of headache, chest pain and nauseating as high concentrations of CO_2 have been shown to be potential inhalation toxicant and asphyxiate (Aerias, 2005, (IVHHN 2005). Significant correlations (table 10) 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 6.78ppm at R1.3 and 15.07ppm at R1.5. CO levels were higher in all locations except at R1.3, R2.2 and R3.2 than the limit of 9ppm for 8h and less than 35ppm limit for 1h set by IDPH. Air quality index in terms of CO shows moderate air quality in R1.3, R2.2 and R3.2. Except at these three rooms, other rooms give unhealthy quality of air for sensitive people in other rooms. The main health effect of this could be headaches, nausea, dizziness, breathlessness, fatigue, coma and death because CO impairs the oxygen binding capacity of hemoglobin which at long exposure can cause cardiovascular diseases (Maura and Bigagli, 2011). This might be why some occupants in the rooms studied complained of allergies, nausea, headaches and body weaknesses. CO showed significant correlations (Table 10) with SO_2 (0.92), PM_{10} (0.81) and ethylbenzene (0.91).

NO_2 levels ranged from 0.39ppm at R3.5 to 1.02ppm at R1.4. Its levels were significantly higher in all locations compared with 0.05ppm set by IDPH. In terms of NO_2, quality of air is 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 because exposure to NO_2 has been reported to enhance asthmatic reactions due to inhaled allergens and to cause respiratory infections and lung cancer. This could not be unconnected to housing structures due to poor ventilation, small apartment size, and frequent use of kerosene stove. (Brauer *et al.*, 2002, Mark *et al.*, 2002, Chauhan *et al.*, 2003, Binod *et al.*, 2010). NO_2 significantly correlates (table 10) with SO_2 (0.70) and PM_{10} (0.74).

Table 5: 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} (μg/m³)	NOISE (dBA)	Relative Humidity (%)	Temp (°C)
R1.1	738.67± 61.99	10.17±1.47	0.51± 0.05	0.22±0.01	0.12± 0.03	94.17± 8.71	64.46±6.07	68.22±4.31	29.73± 1.77
R1.2	861.93±40.13	11.72±0.24	0.34± 0.01	0.24± 0.02	0.08± 0.09	107.21±3.07	61.92±0.76	66.45± 7.28	29.98± 2.56
R1.3	782.15± 23.47	6.78± 0.02	0.47± 0.06	0.12± 0.01	0.11± 0.01	102.20±6.56	89.36±1.27	69.05±2.17	28.20± 3.10
R1.4	892.17± 38.49	12.53± 1.56	1.02± 0.04	0.31± 0.07	nd	126.71±9.14	83.61±1.54	63.78±1.92	28.62± 2.65
R1.5	904.23± 56.16	15.04± 0.08	0.82± 0.03	0.29± 0.02	0.06± 0.01	145.24±12.59	91.76±2.43	67.02±4.11	28.47± 2.87
R2.1	928.67± 96.80	11.17± 1.47	0.65± 0.08	0.23± 0.06	0.08± 0.07	172.83±14.36	78.78±4.16	64.01±5.05	30.08± 1.71
R2.2	972.14± 54.27	8.92± 0.12	0.92± 0.02	0.21± 0.03	0.09± 0.01	185.24±11.67	77.91±6.21	68.69±4.07	28.85± 1.22
R2.3	810.67± 37.82	10.47± 0.24	0.58± 0.03	0.26± 0.01	0.10± 0.03	170.01±10.02	82.24±1.85	66.09±0.14	30.57± 2.47
R2.4	1080.57± 89.81	12.15± 0.06	0.93± 0.07	0.31± 0.05	0.16± 0.04	141.87±15.81	78.29±3.04	66.52±3.76	31.45± 1.68
R2.5	880.05± 73.19	9.42± 0.80	0.67± 0.01	0.28± 0.07	0.13± 0.01	179.15±18.90	81.55±6.18	69.23±1.18	29.77± 4.58
R3.1	872.02± 51.92	10.33± 1.21	0.55± 0.15	0.27± 0.04	0.13± 0.08	140.01±15.99	76.51±6.41	65.84±5.73	28.95± 1.03
R3.2	820.12± 21.19	8.23± 1.21	0.48± 0.04	0.30± 0.01	0.09± 0.03	145.58±17.24	83.97±5.18	68.59±7.65	32.19± 4.82
R3.3	955.21± 60.11	11.42± 0.06	0.83± 0.01	0.19± 0.04	nd	165.17±10.07	75.33±6.22	67.07±3.37	29.93±1.87
R3.4	783.87± 16.03	12.18± 2.47	0.76± 0.05	0.23± 0.03	0.11± 0.02	122.38±14.02	87.27±1.34	69.11±8.01	30.12± 5.47
R3.5	810.38± 24.46	9.87± 0.07	0.39± 0.06	0.29± 0.02	0.08± 0.01	154.56±9.38	79.04±3.49	68.99±1.31	29.54± 2.65
IDPH standard	1000	10-8h 35-1h	0.05	0.5	0.01	150		60	

*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 ≤10μm.

Table 6: 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	B
R1.2	C	-	D	B
R1.3	B	-	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	C
R2.4	C	E	E	B
R2.5	C	E	D	C
	MUSHIN			
R3.1	C	-	D	B
R3.2	B	-	D	B
R3.3	C	E	C	C
R3.4	C	E	D	B
R3.5	C	-	D	B

SO_2 concentrations were in the range 0.12ppm at R1.3 to 0.29ppm at R3.5. SO_2 concentrations in all locations fall below the standard (0.5ppm) 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 (table 10) with PM_{10} (0.70) and ethylbenzene (0.72).

Table 7: Concentrations of volatile organic compounds measured in the study locations. (n=36)

LOCATION	VOLATILE ORGANIC COMPOUNDS (μgm^{-3})						
	BENZENE	TOLUENE	ETHYL-BENZNE	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 8: Estimated hazard quotients of volatile organic compounds studied.

LOCATION	VOLATILE ORGANIC COMPOUNDS					
	BENZENE	TOLUENE	ETHYLBENZNE	XYLENE*	FORMALDEHYDE	CARBONTETRACHLORIDE
R1.1	0.65	0.022	0.012	1.36	18.28	3.13
R1.2	0.87	0.033	0.018	1.09	29.86	2.96
R1.3	0.39	0.042	0.011	1.22	19.99	4.04
R1.4	0.61	0.036	0.016	1.29	22.42	3.38
R1.5	0.56	0.021	0.021	1.61	24.19	2.53
R2.1	0.93	0.015	0.008	1.21	31.16	2.86
R2.2	1.54	0.040	0.010	1.30	27.71	3.18
R2.3	0.53	0.045	0.010	1.33	28.92	2.72
R2.4	0.24	0.031	0.008	1.39	25.49	3.44
R2.5	0.41	0.058	0.016	1.27	32.88	4.19
R3.1	1.66	0.004	0.017	3.13	21.68	3.66
R3.2	0.71	0.020	0.021	2.23	24.35	4.78
R3.3	1.26	0.013	0.013	2.71	14.19	4.19
R3.4	1.06	0.030	0.009	1.19	19.67	3.80
R3.5	1.44	0.045	0.025	2.13	20.43	3.40

Table 9: Cancer risks of benzene, formaldehyde and carbontetrachloride measured at three locations of study

LOCATION	VOLATILE ORGANIC COMPOUNDS		
	BENZENE	**FORMALDEHYDE**	**CARBONTETRACHLORIDE**
R1.1	1.53×10^{-4}	7.13×10^{-4}	5.64×10^{-3}
R1.2	2.04×10^{-4}	1.16×10^{-3}	5.32×10^{-3}
R1.3	9.11×10^{-5}	7.80×10^{-4}	7.28×10^{-3}
R1.4	1.41×10^{-4}	8.74×10^{-4}	6.09×10^{-3}
R1.5	1.30×10^{-4}	9.43×10^{-4}	4.56×10^{-3}
R2.1	2.17×10^{-4}	1.22×10^{-3}	5.15×10^{-3}
R2.2	3.61×10^{-4}	1.08×10^{-3}	5.72×10^{-3}
R2.3	1.23×10^{-4}	1.13×10^{-3}	4.89×10^{-3}
R2.4	5.51×10^{-5}	9.94×10^{-4}	6.19×10^{-3}
R2.5	9.49×10^{-5}	1.28×10^{-3}	7.55×10^{-3}
R3.1	3.89×10^{-3}	8.45×10^{-4}	6.58×10^{-3}
R3.2	1.66×10^{-4}	9.50×10^{-4}	8.55×10^{-3}
R3.3	2.94×10^{-4}	5.53×10^{-4}	7.55×10^{-3}
R3.4	2.47×10^{-4}	7.67×10^{-4}	6.84×10^{-3}
R3.5	3.37×10^{-4}	7.97×10^{-4}	6.12×10^{-3}

Table 10: Correlation matrix of the pollutants

	CO_2	**CO**	**NO_2**	**SO_2**	**H_2S**	**PM_{10}**	**BEN**	**TOL**	**ETHYL**	**XYLEN**	**FORM**	**CCl_4**	**TVOC**
CO_2	1												
CO	**0.78**	1											
NO_2	0.59	0.56	1										
SO_2	**0.73**	**0.92**	**0.70**	1									
H_2S	-0.83	-0.61	-0.84	-0.78	1								
PM_{10}	**0.88**	**0.81**	**0.74**	**0.70**	-0.70	1							
BEN	0.21	0.40	-0.30	0.44	-0.10	-0.13	1						
TOL	-0.03	-0.61	-0.12	-0.46	-0.15	-0.27	-0.26	1					
ETHYL	**0.86**	**0.91**	0.36	**0.72**	-0.49	**0.85**	0.34	-0.44	1				
XYLEN	0.24	0.57	0.55	0.41	-0.13	0.66	-0.38	-0.72	0.48	1			
FORM	**0.66**	0.47	-0.19	0.36	-0.30	0.30	**0.70**	0.08	**0.67**	-0.32	1		
CCl_4	-0.50	-0.89	-0.18	-0.72	0.21	-0.55	-0.56	**0.82**	-0.84	-0.54	-0.48	1	
TVOC	0.09	0.59	0.15	0.10	-0.98	**0.73**	**0.72**	**0.65**	0.56	**0.97**	0.43	-0.19	1

Significant correlations are in bold format. CO_2: Carbondioxide, CO: Carbonmonoxide, NO_2: Nitrogendioxide, SO_2: Sulphurdioxide, H_2S: Hydrogensuplhide, PM_{10}: Particulate matters ≤10μm, BEN: Benzene, TOL: Toluene, ETHYL: Ethylbenzene, XYLEN: Xylene, FORM: Formaldehyde, CCl_4: Carbontetrachloride, TVOC: total volatile organic compounds

Table 11: Factor analysis of pollutants measured

POLLUTANT	**COMPONENT**			COMMUNALITY
	F1	**F2**	**F3**	
CO_2	**0.95**	0.17	0.16	.955
CO	**0.68**	**0.71**	0.23	.999
NO_2	**0.75**	0.24	-0.47	.859
SO_2	**0.73**	0.53	0.22	.855
H_2S	-0.95	0.03	0.04	.905
PM_{10}	**0.82**	0.46	-0.22	.938
Benzene	0.08	0.17	**0.96**	.954
Toluene	0.16	-0.98	-0.08	.985
Ethylbenzene	**0.69**	0.58	0.28	.866
Xylene	0.17	**0.83**	-0.53	.991
Formaldehyde	0.48	-0.03	**0.78**	.844
CCl_4	-0.29	**0.85**	-0.43	.994
TVOC	**0.99**	-0.10	0.01	.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, and significant values are in bold; and only factors with eigenvalue≥1shown. CO_2: Carbondioxide, CO: Carbonmonoxide, NO_2: Nitrogendioxide, SO_2: Sulphurdioxide, H_2S: Hydrogensuplhide, PM_{10}: Particulate matters ≤10μm, CCl_4: Carbontetrachloride,

TVOC: total volatile organic compounds H_2S levels range from not detected (nd) at R1.4 and R3.3 to 0.16ppm at R2.4. The levels of H_2S where detected were majorly above the limit of 0.01ppm set by IDPH. Exposure to H_2S has been reported to cause loss of consciousness, neurobehavioural defects and death (Inserra *et al.*, 2004).

PM_{10} was highest with 185.24μg/m^3 at R2.2 and lowest with 94.17μg/m^3 at R1.1. Majority of rooms in location two (R2) have values higher than 150 μg/m^3 set by IDPH. Except at location two (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 associated with increased respiratory symptoms and production of an inflammatory response on exposure to human lungs (Kohli *et al.*, 2011). PM_{10} correlates significantly with ethylbenzene (0.85) and TVOC (0.73).

Noise levels range from 64.46dB at R1.1 to 89.36dB at R1.3. Noise levels in some of these rooms were high and could account for some aggressive behaviour under slight provocation. Noise has been investigated to cause psychological stress, deafness, aggressive behavior and loss of attentiveness (Hygge and Knez, 2001, Osuntogun and Okoku, 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, Stryjakowska-Sekulska *et al.*, 2007).

Volatile organic compounds (VOC):

Table 7 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 19.60μgm^{-3} at R1.1 to 49.87μgm^{-3} at R3.1. These values were higher than 16.1μgm^{-3} limit of benzene set by HKIAQ, (1999) (Lee *et al.*, 2002). Benzene is a known carcinogen which can cause central nervous damage, leukemia, rapid heart rate, dizziness, unconsciousness and death (ATSDR 2007a, Zhang *et al.*, 2009, Leusch *et al.*, 2010). Benzene significantly correlates with formaldehyde (0.70) and significantly contributes to TVOC (0.72).

Concentrations of toluene ranged from 1.31μgm^{-3} at R3.1 to 13.83μgm^{-3} at R3.5. The values measured were all below the limit of 1092μgm^{-3} set by HKIAQ, (1999) (Lee *et al.*, 2002). The lower values do not exonerate toluene from causing hazards because is known to affect brain, kidney and nervous (ATSDR 2000, Leusch and Bartkow, 2010). Toluene showed significant correlations with carbontetrachloride (0.82) and averagely contributed to TVOC (0.65). Ethylbenzene was lowest at R2.1 with 8.42μgm^{-3} and highest at R3.5 with 25.34μgm^{-3}. These concentrations were lower than 1447μgm^{-3} limit of HKIAQ, (1999) (Lee *et al.*, 2002). Ethylbenzene has been investigated to cause enlargement of liver, kidney and irreversible damage to ears (Tam and Neumann, 2004, ATSDR 2007b, Leusch and Bartkow, 2010). Ethylbenzene averagely correlates with formaldehyde (0.67).

Xylene concentrations varied from 109.15μgm^{-3} at R1.2 to 312.51μgm^{-3} at R3.1. They were all lower than 1447μgm^{-3} limit set by HKIAQ, (1999) (Lee *et al.*, 2002). Xylenes have been reported to affect nervous system and cause lack of muscle coordination, confusion, dizziness, irritation of eyes and respiratory tracts (ATSDR 2007c, Leusch and Bartkow, 2010). Xylene had highest significant contribution to TVOC (0.97).

42.57μgm^{-3} at R3.3 and 98.63μgm^{-3} at R2.5 were the lowest and highest concentrations of formaldehyde measured respectively in this study. Concentrations measured were all higher than 30μgm^{-3} limit by HKIAQ, (1999) (Lee *et al.*, 2002). Formaldehyde is a suspected carcinogen which affects the nervous system and brain (Zhang *et al.*, 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 101.32μgm^{-3} at R1.5 to 189.92μgm^{-3} at R3.2. Except at R1.5, other concentrations of carbontetrachloride were higher than 103μgm^{-3} limit of HKIAQ, (1999) (Lee *et al.*, 2002). Carbontetrachloride has been reported to damage liver, kidney, lung and intestine (Karthikeyan, *et al.*, 2006, Edewor *et al.*, 2007).

TVOC had lowest concentration at R1.1 with 602.41 μgm^{-3} and highest at R3.2 with 921.50μgm^{-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)

Cancer and non-carcinogenic hazard ratio:

Hazard quotients and estimated cancer risks of volatile organic compounds measured in this study are shown in tables 8 and 9 respectively. Hazard quotient (HQ) >1, indicates that long term exposure to these compounds may result in adverse effects on the occupants (Huang *et al.*, 2011, Zhang *et al.*, 2012). All HQ of xylene, formaldehyde, carbontetrachloride and benzene at R2.2, R3.1, R3.3, R3.4 and R3.5 were higher than unity. Formaldehyde in R2.5 has the highest HQ suggesting that the occupants' exposure to these might result in adverse health effects.

All estimated cancer risks from this study exceeded $1x10^{-6}$ indicating life-time risks of cancer. Cancer risk was highest with carbontetrachloride at R3.2 and lowest with benzene at R2.4. Some of the VOC measured have been found to exceed the limit as obtained in this study (Huang *et al.*, 2011, Zhang *et al.*, 2012).

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 11. Three factors were extracted by PCA and they accounted for 93.10% of total variance (eigenvalue ≥ 1). F1 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, Curtis *et al.*, 2006, Padhi and Padhy, 2008, Padhi *et al.*, 2009). F2 with variance 23.98% correlated with CO, xylene and CCl_4, was identified as a factor representing insecticide usage, smokes and evaporation from gasoline powered-generator (Hoddinott and Lee, 2000, Padhi *et al.*, 2009, Logue *et al.*, 2011, Zhou *et al.*, 2011). F3, 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, 2011, 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.

Conclusion

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.

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