Assessment Of Formaldehyde Levels And Its Health Effects In Some Selected Residential Homes And Offices In Ashanti Region, Ghana

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***Abstract*—Pressed wood products, carpets, cleaning products such as detergents and disinfectants, and furniture are significant sources of formaldehyde in residential homes and offices. Due to formaldehyde's carcinogenicity, it has brought into question the impact of indoor air pollutants and indoor air quality. This poses a health risk to the workers and residents in offices and residential homes. This study measures the formaldehyde levels both indoor and outdoor at some selected offices and residential homes. Air samples were taken from selected offices, bedrooms, halls, corridors and kitchens using the 3-methyl-2-benzothiazolinone hydrazine hydrochloride method. Temperature and relative humidity were also measured and a survey on the potential formaldehyde sources in these facilities and health effects were administered to respondents at the same time. Formaldehyde levels recorded for homes ranged between 20 and 430 μg/m^3. At a significant level of 0.05 (5%), no significant difference was found between concentrations of formaldehyde in bedrooms and halls. Significant positive correlations ($p < 0.05$) were found between temperatures and the formaldehyde concentrations in the kitchens, bedrooms, and living rooms. The type of fuel used in these kitchens for cooking showed a positive correlation of 0.011 ($p < 0.05$) with the level of formaldehyde concentration. Indoor formaldehyde concentration recorded for homes ranged between 60 and 430 μg/m^3 which exceeds the World Health Organization's recommended permissible limit of 100 μg/m^3 for homes. The concentrations of formaldehyde recorded for the sampled air from offices ranged between 45 and 399 μg/m^3. Similarly, a positive correlation ($p<0.05$) between relative humidity, temperature and concentrations of formaldehyde was observed. Analysis of the survey showed that the health effect that was complained frequently by residents was a headache. Similarly, some workers in offices complained of headaches. The correlation matrix analysis conducted in this study indicated that homes and offices that use cleaning products such as detergents and disinfectants recorded high levels of formaldehyde. The hazard quotient (HQ) values calculated ranged from 0.1 – 3.2.**

Keywords—Indoor air quality, temperature, carcinogen

Introduction

Formaldehyde is a compound that occurs naturally in the environment and it is the most abundant aldehyde. Formaldehyde is the colourless, harmful and readily polymerised gas at normal room temperature. It has a sharp, strong and irritating odour. Formaldehyde, through oxidation of hydrocarbons, can be formed naturally in the troposphere. It has a molecular weight of 30.03 and soluble in ethers and alcohols and also soluble in water around 400 g/L at 20 °C. Formaldehyde can readily polymerise to a 65-75 % formaldehyde air mixture in the presence of air and moisture at room temperature which is readily flammable (WHO 1989). At temperatures above 150 °C, formaldehyde decomposes into methanol and carbon monoxide and under atmospheric conditions, formaldehyde is photo-oxidized in sunlight to carbon dioxide.

Commercially, formaldehyde is produced from methanol. A metal catalyst which copper was previously used but currently, silver is used in a primary methanol oxidation process in producing formaldehyde. In this process, partial oxidation and dehydrogenation with air is carried out in the presence of silver crystals serving as the catalyst and steam excess at 600 – 650 °C. Formaldehyde is produced industrially worldwide and it finds its use in the manufacture of disinfectants and fixatives, germicides, insecticides or as a preservative in lots of consumer products (Haghighat and De Bellis 1998).

Air pollution occurs when gases, dust particles, fumes or smoke or odour are introduced into the atmosphere in a way that makes it harmful to living organisms. Pollution of the environment has become one of the major problems the world has been battling with currently. Pollution generally has damaging effects on both living things and the environment. Primary sources of indoor air pollution include bioaerosols and volatile organic compounds which include benzene and formaldehyde. When primary pollutants in the air mix up in a chemical reaction, they form more harmful chemicals such as smog and ozone. The effects of air pollution are alarming as they are known to cause several respiratory and heart conditions along with cancer, pneumonia, asthma and even death (Kuwabara et al. 2007).

Formaldehyde can be formed basically by both natural and human activities. Some natural sources that release formaldehyde include volcanoes and biomass decomposition. Human-generated sources of formaldehyde may include fuel combustion from traffic and on-site industrial emission (Kaden et al. 2010). These products and uses are the major indirect sources of formaldehyde, particularly indoors. Secondary formation of formaldehyde which occurs in air through the oxidation of volatile organic compounds and reactions between ozone which is normally from outdoors (Kaden et al. 2010). Secondary chemical processes contribution to outdoor and indoor volatile organic compounds is still not fully known (Kaden et al. 2010).

Indoor air pollution caused by formaldehyde may be through combustion processes such as the use of unvented gas cookers, heating, smoking and candle or incense burning (Salthammer et al. 2010). Moreover, major sources of formaldehyde in non-smoking facilities appear to be building materials and consumer products such as furniture, paints and carpets that emit formaldehyde (Kelly et al. 1999). It is observed that new buildings with high relative humidity and high temperatures have high levels of formaldehyde but these levels diminish after several months (Haghighat and De Bellis 1998).

The main sources of indoor air formaldehyde in homes and offices include furniture and wooden products containing formaldehyde based-resins such as particle board, plywood and medium density fibre board. Paints glues, wallpapers, textiles, insulating materials, adhesives lacquers and vanishes also release formaldehyde (Nazaroff and Weschler 2004). Cleaning products such as detergents, disinfectants, softeners, carpet cleaners, shoe products, cosmetics such as nail hardeners, nail polish and vanishes, shampoos, liquid soaps, electronic equipment such as computers and photocopiers and some items such as insecticides and paper products all release formaldehyde into the environment (Uhde and Salthammer 2007).

Chemical products that contain formaldehyde and formaldehyde releasers (Flyvholm and Andersen 1993), cleaning activities (Wolkoff et al. 1998), household products (Singer et al. 2006) and consumer products materials (Destaillats et al. 2006) studies have shown that in the presence of ozone release formaldehyde into the atmosphere. Indoor materials such as carpet, wall, floor, cooking oil, and wood-based products (Wang and Morrison 2006), textiles, heaters, burners, cigarettes (Maroni et al. 1995), Polyvinyl chloride, carpet, wall coverings, rubber foam backing (Yu and Crump 1998), VOC mixtures and polymeric materials (Zhang et al. 1994) all in the presence of ozone release formaldehyde into the indoor air. Portable air cleaners with and without air fresheners (Waring et al. 2008), materials aircraft cabin materials and clothing fabrics (Coleman et al. 2008), newspaper, books, journals (Salthammer et al. 2010), preservative anatomical dissection course (Wantke et al. 2000) all release formaldehyde into the atmosphere.

With respect to all the possible indoor sources of formaldehyde, it makes it difficult to identify the major ones that contribute to indoor levels. During a large scale indoor survey that was conducted by Raw et al. (2004) between 1997 and 1999 in eight hundred and seventy-six homes in the United Kingdom, it was found that depending on the age of the building, the presence of particle board flooring in the home was the second most important determinant of indoor concentration (Raw et al. 2004). In another research conducted by Clarisse et al. (2003), formaldehyde concentrations measured in the bedroom, the kitchen and living room of sixty-one Parisian flats with no previous history of complaint about the olfactory nuisance. They found that indoor levels of formaldehyde depended on the age of the wall or flooring coverings such as renovations less than one-year-old, smoking and ambient parameters such as carbon dioxide levels and temperature (Clarisse et al. 2003).

Gilbert et al. (2006) measured formaldehyde levels in ninety-six homes in research conducted in Quebec City, Canada. Levels of formaldehyde were negatively correlated with air exchange rates. They were significantly elevated in homes heated by electricity, in those with new wooden or melamine furniture purchased in the previous twelve months. Similarly, in those where paintings or vanishing had been done in the previous twelve months (Gilbert et al., 2006). Formaldehyde concentrations in homes, offices or any facility vary according to the age of the building, temperature and relative humidity of the facility, ventilation and season (Haghighat and De Bellis 1998; Raw et al. 2004).

There are reports in research studies that short term exposure to formaldehyde can cause eye, nose, throat and skin irritations whereas long term exposure has been associated with certain cancers as well as asthma. In the upper respiratory tract, irritation effects begin at concentrations as low 0.1 ppm but these effects become more prevalent at concentrations of 0.2 ppm (Liu et al. 1991). Symptoms in the lower airways such as cough, chest tightness, and wheeze are observed at concentrations above 5 ppm, but some of these symptoms may occur in the presence of fine particles at lower concentrations of 0.07 ppm (Liu et al. 1991).

To protect the population from the health effects of formaldehyde several safety and occupational health authorities worldwide have proposed permissible exposure levels of formaldehyde through inhalation. They have set occupational threshold limit values (TLV) which are generally categorised as time-weighted average (TWA), short term exposure limit (STEL) and ceiling (C) values. Ceiling values define the exposure limit which should not be exceeded at any time (Salthammer et al. 2010). The STEL and permissible exposure limit rime-weighted average (PEL-TWA) set by the Occupational Safety and Health Administration (OSHA) for formaldehyde is 2 ppm in 15 minutes and at 0.75 ppm respectively. WHO (1989) recommends that indoor formaldehyde concentration should be 0.08 ppm whereas California Air Resources Board recommends a target level of 0.05 ppm for homes but such guidelines are not available in Ghana. Khoder et al. (2000) report a level of 0.100ppm of formaldehyde in older homes and 0.147 ppm in newer homes in a research conducted in Greater Cairo which is all above the recommended limits set by health organisations. There is the need to investigate this in Ghana since data for formaldehyde emission are needed for setting standards of indoor exposures, health risks, and measures for reducing risk in Ghana.

Materials and methods

Indoor and outdoor measurements of formaldehyde concentrations were made and a total of 34 samples were taken from bedrooms, kitchens, living rooms and corridors of eight (8) different homes. Sixteen samples were also taken from offices. The indoor samples were collected at approximately 1.5 m above the floor.

Chemical Analysis

Reagents and Instruments

Absorbing solution was prepared from 3-methyl-2-benzothiazolinone hydrazine hydrochloride (MBTH) (Sigma-Aldrich Chemie GmbH, Steinheim, Germany). The oxidizing solution was prepared from Sulfamic acid ( ) and ferric chloride ( ). Spectrophotometry (Shimadzu mini UV/Visible Spectrophotometer model 1240, Shimadzu Corporation, Japan) was used for the determination of absorbance. The total aldehyde in air was collected in 0.05 % aqueous solution of MBTH system service innovation incorporation air sampler model 1000i ( ). Relative humidity and atmospheric pressure were measured using 433 MHz electronic weather station. The resulting azine was then oxidized by a ferric chloride-sulfamic acid solution which can be measured at 628 nm using spectrometry. Formaldehyde solution (DB11 Laboratory supplies, England).

Air Sampling

The concentration of total aldehyde is calculated in terms of formaldehyde. Air samples were calculated in glass impinger containing 35 ml of 0.05 % MBTH solution using the system service innovation incorporation air sampler model 1000i calibrated to draw 0.5 L of air per minute. Sampling was done for 30 minutes (15 L of air). After each sampling time, the volume of the absorbing solution was made to 35 ml if there were any losses as a result of evaporation. At the same time, the temperature, relative humidity and atmospheric pressure were measured using 433 MHz electronic weather station. Samples were then transferred into clean sample bottles and sealed and taken to the laboratory for analysis.

Analysis of Samples

Ten millimetres of the sample solution was transferred into a clean glass stoppered tube washed with distilled water and an equal volume of unexposed reagent and distilled water were placed in a second clean tube to serve as a blank.

Two millimetres of the oxidizing solution was prepared from 1.0 g of ferric chloride and 1.6 g of Sulfamic acid dissolved in 100 ml of distilled water was added to the sample solution and blank and mixed well. After allowing to stand for at least 12 minutes, the absorbance was determined at 628 nm against the reagent blank using Shimadzu mini UV/visible spectrophotometer model 1240.

To prepare the calibration solution, a stock formaldehyde solution of concentration 402402 mg/L was used to prepare formaldehyde standard solution of concentration 4000 mg/L. Formaldehyde working standard solutions of concentrations 0.5, 1.0, 1.5, 2.0, 2.5 mg/L were prepared from the formaldehyde standard solution.

To a clean tube, 5 ml of 0.05 % MBTH solution, 5 ml of standard formaldehyde solution and 2 ml of oxidizing solutions were added. This was used as a reagent blank.

A series of questions and other prompts in the form of a survey were used to gather information about the facilities to know the specific materials found in these facilities that emit formaldehyde. It was also used to get information about the health conditions of workers and residents of facilities where samples were taken.

Results and discussion

Formaldehyde concentration

A total of 34 samples were taken from bedrooms, kitchens, living rooms and corridors of eight (8) different homes. There is a positive correlation ($p<0.05$) between the concentration of formaldehyde measured and temperature for the residential homes. This implies that an increase in temperature is one of the factors that will cause an increase in the level formaldehyde concentration in the homes as observed from the correlation matrix. Majority of the homes had slightly higher concentrations due to the increase in temperature.

A second factor that was shown to be a determinant of formaldehyde concentration was the use of house cleaning products and disinfectants. There was a positive correlation at a significant level of ($p< 0.05$) between the concentration of formaldehyde recorded and the use of house cleaning products such as detergents and disinfectants.

At a significant level of 0.05, no significant difference was found between the concentrations of formaldehyde recorded in bedrooms and halls. This is in agreement with Khoder et al. (2000) who found no significant differences between the concentrations of formaldehyde in the living rooms and bedrooms. Significant positive correlations ($p < 0.05$) were found between the formaldehyde concentrations in the kitchens, bedrooms and living rooms and temperature as reported by Haghighat and De Bellis (1998). Raw et al. (2004) also reported from their research high temperatures causing an increase in the levels of formaldehyde in homes. Formaldehyde concentrations recorded in the bedrooms and living rooms were slightly higher as compared to the kitchen shown in **Table 3** above, except in Anwomaso, Akwatia line, Nkawie and Mankranso where relatively higher concentrations were recorded in the kitchen.

Table 3. Indoor and outdoor formaldehyde concentrations (μg/m^3) in the kitchens, bedrooms, living rooms and corridors

Site	Kitchens	Bedrooms	Living rooms	Corridors
Anwomaso	220	127	70	80
Akwatia Line	322	125	-	44
Bekwai	90	270	90	50
Nkawie	215	122	-	62
Afari	76	229	-	90
Kwamo	70	191	360	20
Mankranso	263	190	-	83
Konongo	89	157	330	49

This could be explained from the free exchange of air as this is was also reported by Raw et al. (2004) who conducted a research on pollutants in English homes and reported that air exchange rates affected the concentrations of formaldehyde in English homes. Air exchange rates were not measured in this study. From the study, the type of fuel used in these kitchens for cooking showed a positive correlation which is lower than the ($p = 0.05$) between the level of formaldehyde concentration and fuel type in the kitchen. This means that the type of fuel used in the kitchen is another factor that has a direct influence on the level of formaldehyde measured in the kitchen and this is in consonance with findings from a research conducted in China by Zhang and Smith (1999) which revealed that all tested cookstoves and fuel types had significant positive correlation with formaldehyde concentration. This was evident in the kitchen at Akwatia line that recorded a concentration of 322 μg/m^3 and had 6 gas stoves that used LPG and 2 coal pots that used charcoal as fuel. This kitchen had an entrance and two small windows making the ventilation poor. This could account for the high level of formaldehyde concentration since the size of this kitchen was almost the same size as that found in other homes that used only one gas stove and one kind of fuel for cooking. The situation was not different from Mankranso because it was also a kitchen used by several occupants of the house at the same time. From **Table 3**, it can be noticed that Kwamo residency recorded the minimum level of formaldehyde of 70 μg/m^3 for the kitchens. The Kwamo residency had a well-ventilated kitchen and used only one type of fuel which is LPG. All the kitchens used only one type of fuel except Akwatia line, Mankranso and Nkawie. It can be seen from the results that, kitchens that employed both LPG and charcoal recorded high concentrations of formaldehyde. Bekwai residency recorded a concentration of formaldehyde similar to that of its living room because the living room opens into the kitchen and this causes air to be mixed up in this facility. This means the frequent use of liquefied petroleum gas and poor ventilation contributed to the high levels of formaldehyde in Akwatia line, Mankranso and Anwomaso kitchens.

Relatively low concentrations were recorded for corridors as compared to the concentrations that were measured from the kitchens, halls and bedrooms in these homes. The reason for these low values could be the free exchange of air or good ventilation in the corridors. There was no significant correlation between the levels of formaldehyde measured in the halls and the levels of formaldehyde measured in the corridors of these homes. But a significant difference ($p < 0.05$) was recorded for all homes between the levels of formaldehyde measured in halls and corridors (outdoor). This is in consonance with Khoder et al. (2000) in a research conducted in Greater Cairo that found out that level of formaldehyde in the indoor environment is higher than that recorded for the outdoor environment. The maximum and minimum formaldehyde concentration recorded for corridors (outdoor) were 90 and 20 µg/m^3.

A bedroom sampled from Kwamo recorded the maximum concentration of 430 µg/m^3 at a temperature of 32.7 ^{0}C for formaldehyde, and this was the highest concentration recorded for all samples taken from homes. Bedrooms had furnitures such as bed, tables, chairs, pressed wood products such as plywood ceiling, wardrobes, cosmetics, and paints. From literature, Salthammer et al. (2010) reported that these products are important sources of formaldehyde in the homes and contribute to formaldehyde concentrations in the homes. All these have been confirmed from the study to be important sources of formaldehyde in the bedrooms. The study shows that there is a positive correlation though not significant r = 0.351 ($p > 0.05$) between the concentration of formaldehyde in the facility and products that are used in those facilities. The high concentration recorded for a bedroom at Kwamo can be attributed to poor ventilation, high temperature and presence of the sources of formaldehyde. The same could be the explanation for the levels of formaldehyde recorded at Bekwai. All important sources of formaldehyde in the homes that were stated in this study was available in this room. Good ventilation, low temperature and lower number of important sources of formaldehyde contributed to the low level of formaldehyde concentration recorded for bedrooms in Anwomaso and Akwatia line as confirmed by Haghighat and De Bellis (1998). He also determined that temperature had a significant impact on the levels of formaldehyde concentration in research conducted on material emission rates.

The highest and lowest concentration recorded in living rooms sampled were 360 and 70 µg/m^3. Hall sampled at Kwamo has a living room and a dining area together and that recorded the highest concentration. Residents had occupied the building for less than a year. New furniture had been purchased and renovation that had been done in this facility included a change of ceiling, painting and carpets. The high concentration that was recorded for a new home has also been reported by Raw et al. (2004). Formaldehyde exposure in homes is likely to be of concern only in new homes. From the 3-day mean concentrations in six homes, 0.7% of the total recorded by Raw et al. (2004) exceeded the WHO 30 minutes air quality guideline of 100 µg/m^3. Air fresheners and other products such as computers, printers, liquid soaps and insecticides were all used in this facility. Conversely, the hall at Anwomaso that had the minimum concentration recorded had been occupied for more than eleven years and had not seen any renovation for the past three years. Furniture was old, computers, printers and photocopiers were absent in this facility.

From **Table 6**, it can be observed that formaldehyde concentration measured for the indoor homes is higher as compared to the outdoor concentrations measured in these homes.

Table 6. Range of formaldehyde concentration for indoor and outdoor (Homes)

Location	Formaldehyde Concentration (µg/m^3)
Indoor	60 – 430
Outdoor	20 – 90

The indoor formaldehyde concentration recorded ranged from 60 – 430 µg/m^3 and this concentration exceed the WHO's recommended permissible limit of 100 µg/m^3 for homes. The indoor formaldehyde level set by Office of Environmental Health Hazard Assessment of the Californian Environmental Protection Agency (OEHHA) for acute and non-carcinogenic reference exposure limit (REL) is 55 µg/m^3 and 9 µg/m^3 respectively and the level of formaldehyde determined for homes in this study far exceeds these set limits. The mean outdoor level of formaldehyde recorded for homes was within the permissible limits set by health and regulatory organizations. Exposure in the home represents an important proportion of total exposure especially for the aged and children who are always at home, the total of their annual exposure. Humans spend most of their time indoors and being exposed to these high levels of formaldehyde for long periods may cause acute effects such as eyes, nose and throat irritations. Some residents complained of a headache which was persistent. Kotzias et al. (2005) report from the INDEX project for critical appraisal of the setting and implementation of indoor exposure in the EU that children may be more sensitive to formaldehyde respiratory toxicity than adults and it is considered a chemical of concern at levels exceeding 1 µg/m^3. This raises concern about children's exposure to formaldehyde in homes.

The concentrations of formaldehyde recorded for the sampled air from offices ranged from 45 to 399 µg/m^3 as shown in **Table 8**.

Table 8. Results of analysis of samples from Offices

Offices	Concentration (µg/m^3)
Plus lab Supervisors Office (Mankranso)	231
Presby JHS Headmaster's Office (Asawase)	90
Mankranso SHS, Accounts Office (Mankranso)	230
Wesley High School ICT Lab (Bekwai)	143
Wesley High School, Assistant Headmaster's Office (Bekwai)	179
Sinapi Susu (Manager's Office, Nkawie)	104
Wesley High School, Assistant Headmistress's Office (Konongo)	77
Babs Business Centre (Obuasi)	219
SGN Susu (Obuasi)	104
KNUST Chemistry Department Instrumentation Lab 1 (Kumasi)	399
KNUST Chemistry Department Instrumentation Lab 2 (Kumasi)	119
Wesley High School, Staff Common Room (Bekwai)	120
KNUST, SMS (Boardroom, Kumasi)	45
Wesley High School, Assistant Headmaster's Office (Konongo)	205
Mercury Lab, KNUST Chemistry Department (Kumasi)	269
Office Corridor (SMS, Kumasi)	159

Table 7 shows the maximum and minimum concentrations recorded for formaldehyde levels were 399 and 45 µg/m^3.

Table 7. Summary statistics (Quantitative data) for offices

Variable	Observations	Minimum	Maximum
Concentration (µg/m^3)	16	45.000	399.000
Temperature (°C)	16	25.800	34.400
Relative Humidity (%)	16	43.000	60.000

There is a positive correlation r = 0.126 ($p < 0.05$) though not significant between the relative humidity, temperature and concentrations of formaldehyde measured. These findings are in agreement with a research work conducted by Haghighat and De Bellis (1998) on the emission rate of volatile organic compounds from materials which indicated that both the temperature and relative humidity had a significant effect on the emissions of volatile organic compounds from materials in buildings. The research by Haghighat and De Bellis (1998) explains that as the indoor air temperature of the environment increased, the total volatile organic compounds (TVOC) emission rates also increased for both the paint and varnish. At temperatures above 35°C and 65% relative humidity materials tend to release high levels of formaldehyde over time. This is also consistent with other findings from Khoder et al. (2000) who also reported significant positive correlations between formaldehyde concentration and air temperature and relative humidity in some indoor environments in Greater Cairo. The correlation analysis conducted in this study indicates that cleaning products such as detergents and disinfectants have a positive correlation of r = 0.351 at a confidence interval of 95% with the concentration of formaldehyde measured in these offices. In a research conducted by (Nazaroff and Weschler 2004) in the United States on cleaning products and air fresheners; exposure to primary and secondary air pollutants reported that certain chemicals listed by the state of California as toxic air contaminants (TACs) and as a result they are classified by federal government of the United States as hazardous air pollutants (HAPs). About 65 chemicals species recognized as carcinogens or reproductive toxicants by California's Proposition also includes constituents of certain cleaning products and air fresheners. Many cleaning agents and air fresheners contain chemicals that can react with other air contaminants to generate potentially harmful secondary products such as terpenes that can react rapidly with ozone in indoor air generating many secondary pollutants, including toxic air contaminants such as formaldehyde. This supports the findings in this study. This cleaning products used in offices such as detergents and disinfectants are important sources of formaldehyde in the office. The office at Plus lab mortuary where the supervisor of the facility operated from is just a corridor away from the embalming area of the mortuary. It recorded a concentration of 231 µg/m^3. A curtain is the only boundary that separates this office from the corridor and the embalming room. Air is exchanged freely between the corridor and embalming room since it had no enclosure and that could have accounted for the high concentration recorded.

Instrumentation laboratory 1 at KNUST, Department of Chemistry recorded a concentration of 399 µg/m^3 which is the highest concentration for the offices in this study. This lab is used for the preparation of samples, chemicals and solutions, heating of solutions and analysis and storage of all kinds of samples. Stored samples, cleaning agents and other chemicals could have contributed to the high levels of formaldehyde in this office. It is not well ventilated because it is air-conditioned but the air conditioners are not functioning. About 48% of the offices are naturally ventilated and the remaining are fully air-conditioned.

From **Table 11**, it can be explained that the correlation between the concentration of formaldehyde and HCPDTS, the concentration of formaldehyde and KNOW are all positive while that of concentration and RRRF, concentration and PIF are all negative.

Table 11. Correlation Matrix for possible sources of formaldehyde in offices.

	HCPDTS	RRRF	KNOW	PIF	Concentration (µg/m^3)
HCPDTS	1				
RRRF	0.150	1			
KNOW	0.214	-0.121	1		
PIF	-0.027	0.073	-0.126	1	
Concentration (µg/m^3)	0.351	-0.213	0.395	-0.041	1

This suggests that an increase in HCPDTS and KNOW will increase the level of formaldehyde concentration but this was not significant. Similarly, an increase in RRRF and PIF will decrease the level of formaldehyde concentration and vice versa. House cleaning products such as detergents and disinfectants are used in almost all offices from which samples were taken from and it has a direct effect of increasing the levels of formaldehyde if these products are frequently or always used in the facility. Air fresheners, liquid soaps, insecticides correlated positively with a concentration of formaldehyde, meaning formaldehyde levels will rise as these products are used frequently, but this correlation r = 0.395 ($p>0.05$) was not significant. The products used in the offices that samples were taken from include pressed wood products and furniture. Hodgson et al. (2002) reported a formaldehyde concentration of 94.30 µg/m^3 in a new manufacture study house in a research that was conducted in California to identify the sources of formaldehyde, terpenes and other aldehydes in a new manufactured house. The study house was predominantly furnished with wood and engineered wood products. This is in agreement with this study's finding of furniture and wood pressed products contributing to the sources of formaldehyde. Cosmetics, deodorants, insecticides, photocopiers and other products were part of the listed items on the questionnaire. Users of these offices did not complain about any of the listed health effects associated with exposure to formaldehyde except for two persons who complained about a headache.

Non-Carcinogenic Human Health Risk Study

The levels of formaldehyde determined from the study were used to assess the inhalation risk for human health as workers and inhabitants of these offices and residences inhale air from these facilities. To be able to characterize the non-carcinogenic health risks for humans, calculations of Hazard Quotient (HQ), which is defined as the relation between the predicted exposure concentration and the inhalation reference dose (RfDinh) were done. The RfDinh value of 9.83 µg/m^3 used to calculate HQ was taken from a document of the United States Environmental Protection Agency (Rovira et al. 2016). The hazard quotient values calculated ranged from 0.3 to 2.9. This indicates that about 56.25 % of the workers in these offices that were sampled from are being exposed to higher levels of formaldehyde concentration.

Conclusion

The research identified some products used in the homes and offices such as furniture, computers, paints, cosmetics, deodorants, liquid soap, insecticides and photocopiers as having a positive correlation with the concentration of formaldehyde. This means they are significant sources of formaldehyde in the homes and offices. In residential homes, the maximum formaldehyde concentration measured was 460 µg/m^3 for a bedroom. Temperature also had a positive correlation with concentration measured for homes. The questionnaires that were used to interview workers confirmed that the effects of exposure to formaldehyde were experienced by almost all workers. The hazard quotient calculated to check for the non-carcinogenic human health risk for workers in offices indicated that about 56.25 % hazard quotient values were above the safety limit (HQ = 1). This means that the formaldehyde concentration levels determined from the sampled areas in this study may pose a health risk to workers and inhabitant. The HQ values calculated for the sampled homes ranged between 0.1 and 3.2. Fourteen sampled areas out of the thirty-four representing 41.17% were above the safety limit. The concentration of formaldehyde recorded for residential homes ranged from 20 to 430 µg/m^3, that of offices also ranged from 45 to 399 µg/m^3 and mortuaries formaldehyde concentrations ranged between 14 and 710 µg/m^3 respectively. These concentration that was measured are all above the World Health Organisation (WHO) permissible limit of 100 µg/m^3 for eight hours working period and these also exceed the chronic and acute reference exposure limit set by the Office of Environmental Health Hazard Assessment (OEHHA) for prevention of health risk to humans at 55 µg/m^3 and 9 µg/m^3 respectively. Residents should avoid being in the same room as gas cooking activities takes place or better ventilation should be provided close to the gas cooking appliances. Good ventilation should be employed especially during construction and first two years of occupying a new facility with regards to an office or a home.

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