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Painted Walls: A Possible Contributory Factor to Elevation in Indoor Air Pollution Levels

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ABSTRACT

This study focused on the determination of formaldehyde emission concentration levels of some selected buildings in Rumuolumeni Community, Obio-Akpor Local Government Area of Rivers State, and lies on latitude 4° 65' 44'' north and longitude 6° 35' 51'' east. 10 buildings (five painted and five unpainted buildings) at different locations within Rumuolumeni Community were selected for the study. A formaldehyde concentration monitor was positioned 1.5 meters above the floor of each of the selected buildings to determine the formaldehyde concentration levels every 30 minutes intervals for three hours daily, for a period of two weeks. The geographical locations, indoor relative humidity, and temperature of the selected buildings for the period under study were also taken. The mean values of 0.022 ppm, 0.036 ppm, 0.043 ppm, 0.048 ppm, 0.057 ppm, 0.058 ppm and 0.060 ppm of formaldehyde concentration levels emitted by the selected painted and unpainted buildings for the period under study did not exceed the permissible limits of 0.08 ppm and 0.1 ppm established by WHO and NIOSH respectively. Similarly, the measured values of formaldehyde concentration did not exceed the recommended levels permitted by OSHA and the American Conference of Industrial hygienists of 2 ppm, 0.75 ppm, and 0.3 ppm respectively. However, these values were higher than U.S. NIOSH “recommended time-weighted average exposure limit of 0.016 ppm for workplaces”, and the ATSDR established “chronic inhalation minimal risk level (MRL) of 0.003 ppm (0.004 milligrams per cubic meter, mg/m^3) based on respiratory effects in humans”.

Keywords: Painted walls; Elevation; Indoor air; Pollution levels.

1. INTRODUCTION

Air pollution is a serious environmental problem. The factors that are responsible for this environmental problem are both natural and anthropogenic in nature. Human activities such as the manufacturing of paints and their application on the buildings’ walls and other objects for the purposes of beautification and protection could pose serious health hazards to human beings and his environment the due to the emission of toxic volatile compounds compound called formaldehyde. In Nigeria, not all local paints factories adhere to standards in terms of the quantity of formaldehyde required in the manufacturing of paints, probably, there are no guidelines put in place to regulate the process or if there are guidelines, no proper inspection, monitoring and penalty for defaulters of the set guidelines. More so, assessment of formaldehyde concentration in painted buildings has not been given adequate attention in this part of the globe due lack of awareness on the health effect associated with exposure to this volatile organic compound. More worrisome is the fact that owners of painted buildings are not ready to compromise when issues of estimating formaldehyde concentrations are brought before them.

The discovery of formaldehyde has spanned well over a century. Formaldehyde was realized by technical synthesis of the “dehydration of methanol in 1867 by the German chemist, August Wilhelm von Hofmann” [1]. Thereafter, many industrial uses of formaldehyde emerged. Paint beautifies and offers protection and colour to objects [2]. Similarly, painting on a building increases the real estate value of our homes, hides stains and marks, protects exterior and interior surfaces for longer durability promotes positive energy, and improves homeowner outlook [3]. More so, certain paints when applied to the walls have the potential to heat it, thereby saving energy and reducing CO_2 emissions, cleaning the air we breathe, breaking down chemicals and pollutants, and eliminating harmful pathogens [4]. A fresh coat of paint can work wonders for our homes, and potentially increase their value by thousands of dollars [5]. Paints protect the walls from moisture. In the United States, all kinds of paints that use synthetic polymers like vinyl acrylic and formaldehyde in the production of paint binder resins are commonly called latex paint while the UK is emulsion paint. Latex in the context of paint is not the same as latex from rubber plant [6]. However, a number of authorities such as the European Union Occupational, and the American Environmental Protection Agency (EPA), have also identified formaldehyde as a carcinogenic substance [7]. "The International Agency for Research on Cancer (IARC) classified formaldehyde as a Group 1 carcinogen for humans in 2004" [8].

According to World Health Organization(WHO), indoor exposures to formaldehyde are the major contributor to individual exposures through inhalation, which could lead to adverse health effects as a result of high level of formaldehyde concentration [9]. A study by Lang and Triebig showed that formaldehyde Exposure to indoor air pollution may be responsible for nearly 2 million deaths per year in developing countries [11]. High levels of indoor formaldehyde pollution could emanate from interior decoration of buildings [11]. Materials such as furniture, wall paint, adhesive used in the decoration of residential buildings are responsible for the release of formaldehyde [12]. Studies have shown that formaldehyde concentration is basically a function of the relative number of decorative materials used in the buildings. There is a correlation between indoor pollutant levels and the time decoration was done, the size of the indoor environment and arrangements of furniture [13]. A study on contemporary exposure to formaldehyde and organic solvents during surface coating with acid-curing lacquers and paints in the Norwegian woodworking and furniture industry over a period of 3 years showed that about 10% of the samples analyzed exceeded the Norwegian occupational exposure limit of 0.5 ppm [14].

1.1. Sources of Formaldehyde

The sources formaldehyde in the environment is both natural and man-made. Secondary formation of formaldehyde happens in the atmosphere through oxidation of natural and anthropogenic volatile organic compounds [15]. Formaldehyde is one of the many organic substances that are emitted into the Earth's atmosphere from biogenic origins [16]. Formaldehyde has been observed to be emitted from eucalyptus forests in Portugal when isoprene is broken down [17]. Formaldehyde is produced via isoprene reaction with hydroxyl ion (OH) and nitrogen monoxide (NO) [1]. Formaldehyde concentrations from the range 0.24-0.52 ppb have been detected by Smidt "in forests in the Austrian Alps (920 m) and 0.16-0.30 ppb at a mountaintop site (1758 m)" [1]. Formaldehyde and other aldehydes are formed when hydrocarbons react with O_3 and OH radicals [18]. Formaldehyde is a product of reaction between OH radicals and either isoprene or terpenes spread around foliage [18]. Formaldehyde can also be found in sea water [19]. The sources of formaldehyde are both natural and man-made. Industrial applications, consumer goods, combustion of fossils, and emissions from building materials are some of the anthropogenic sources of formaldehyde [18]. Ordinarily, formaldehyde is not a constituent of gasoline, but a toxic air pollutant that is typically emitted from natural gas-fired internal combustion engines due incomplete combustion [20]. "The concentration of a chemical specie in vehicle exhaust is a function of several factors, including engine type, engine operating conditions, fuel and lubricating oil composition and emission control system" [21]. The furniture industry is experiencing an increase in the use of synthetic materials, resulting in increasing air pollution. Formaldehyde is said to be a part of human's normal metabolic process, and account for about 1.5 ounce [22]. "Most organisms, including humans, naturally produced formaldehyde is physiologically present as a metabolic byproduct in all bodily fluids, cells, and tissues" [23].

Production: China and the United States are the leading global formaldehyde producers and consumers [23]. Report has shown that "more than 65% of the Chinese formaldehyde output is used to produce resins mainly found in wood products - the major source of indoor pollution in China" [24].

1.2. Physical Properties of Formaldehyde

The name formaldehyde emanates from its similarity to formic acid. The pure compound is a colourless and pungent-smelling gas that polymerizes spontaneously into paraformaldehyde. Hence, this compound is stored as an aqueous solution commonly called formalin. It has a mass of 30.00g/mol, a density of 815 kg/m^3, and a boiling point of -19^{o}C. Formaldehyde is soluble in water and in acetone.

Formaldehyde (HCHO), also called methanol, is the simplest of aldehydes (R−CHO), used in large amounts in a variety of chemical manufacturing processes. It is produced principally by the vapor-phase oxidation of methanol and is commonly sold as formalin, a 37 percent aqueous solution.Formaldehyde is said to appear in several forms, and notable among them include molecular formaldehyde, 1,3, 5–trioxane, paraformaldehyde, and methane dio [25].

1.3. Effects of Formaldehyde

Materials like resins, chipboard, plywood, fabrics, and activities such as cigarette smoking, heating and cooking are the main indoor sources of formaldehyde that are posing serious health effects on humans [26]. Formaldehyde vapour may cause irritation, especially the eyes, upper airways and skin when one is expose to it [27]. Workers who involve in materials that contain formaldehyde compound during production stage have been identified as the ones mostly affected by formaldehyde pollution [28].

Studies have shown that there is an association between exposure to formaldehyde and increasing number of blood, brain, and colon cancers related deaths among workers in formaldehyde production industries compare to persons who are not working where formaldehyde is produced [18]. Eye irritation and stinging, throat and nose irritation have been reported with formaldehyde concentration between the range of 0.13–0.45ppm [29]. "In the atmosphere, formaldehyde usually breaks down quickly to create formic acid and carbon monoxide, which can also be harmful substances" [19]. "Formaldehyde is a well-known airborne contaminant causing eye, nose, and throat irritation as well as airway irritation and slight neuropsychologic changes [30].

Formaldehyde poisoning is a disorder brought about by breathing the fumes of formaldehyde resulting in eye, nose, and throat irritation, headaches and skin rashes [31]. Andrzej and others conducted a study on formaldehyde emitted by the internal wall paints at Wrovlaw, Poland [32]. In this study, two kinds of paints were used on 30 different houses [32]. Results indicated that formaldehyde concentration in the paint containing it has an effect on the residents of the houses in which formaldehyde was in the paint mixture [32]. Additionally, paint is said to contribute 17% of the total hazardous waste in the United Kingdom with large quantities ending up in the sewers or mixed with municipal solid waste [33]. In some major cities around the world, it is illegal to discharge oil-based paint down the drains and sewers.

1.4. Methods of Detection of Formaldehyde in Air and Liquid

A number of methods have been designed for detecting formaldehyde in air and liquid. The methods employed in air and aqueous samples are spectrophotometry and high-performance liquid chromatography (HPLC) respectively [34]. Other methods such as "colorimetry, fluorimetry, polarography, gas chromatography (GC), infrared detection, flow injection analysis, and gas detector tubes "can also be employed in the detection of formaldehyde" [34].

1.5. Uses of Formaldehyde

Formaldehyde has many industrial uses such as the production of urea-formaldehyde resins, phenol-formaldehyde resins, melanine resins [35]. Other applications include preservation of biological specimens, grain, seed dressing, soil disinfection, soap preservative, detergents, and many others.

1.6. Indoor Limit

A number of safety and occupational health organizations around the globe have established permissible limits for formaldehyde both in occupational and non-occupational (residential) environments [1]. These occupational and non-occupational threshold limit values are often viewed as time weighted average (TWA), short-term exposure limit (STEL) and ceiling (C) values. The later defines the exposure limit which should not be exceeded at any time [36]. "In the United States, buildings are monitored to ensure that their air does not contain high levels of formaldehyde, which can sometimes be a risk for newly constructed buildings as formaldehyde is used in producing and finishing many building materials" [37]). According Subasi, the indoor formaldehyde concentration level should normally not be above 0.03 ppm [18]. Similarly, WHO has reported "the perception of odour may result in some individuals reporting subjective sensory irritation, and individuals may perceive formaldehyde at concentrations below 0.1 mg/m^3, but this is not considered to be an adverse health effect and thus, a short-term (30-minute) guideline of 0.1 mg/m^3 is recommended as preventing sensory irritation in the general population" [9]. In view of the of the foregoing, "Occupational Safety and Health Administration (OSHA) has set the short-term exposure limit (STEL) for formaldehyde at 2ppm in 15 minutes and the permissible exposure limit time-weighted average (PEL-TWA)" at 0.75ppm [38]. American conference of governmental industrial hygienists (ACGIH) pegged their permissible exposure limit at 0.3ppm. Similarly, "the National Institute for Occupational Safety and Health (NIOSH) established a short-term exposure limit" (STEL) of 0.1ppm and a limit of 0.016ppm for occupational exposure. "The Agency for Toxic Substances and Disease Registry (ATSDR) has established a chronic inhalation minimal risk level (MRL) of 0.003 ppm (0.004 milligrams per cubic meter, mg/m^3) based on respiratory effects in humans. World Health Organization (WHO) established an indoor air quality guideline for short-and long-term exposures to formaldehyde (FA) of 0.1 mg/m3 (0.08 ppm) for all 30-min periods at lifelong exposure" [39]. "Recent environmental requirements restrict the use of volatile organic compounds (VOCs), and alternative means of curing have been developed, generally for industrial purposes" [40].

1.7. Effects of Temperature and Relative Humidity on CHCO emission concentration

"Humidity is one of the main environmental factors affecting the emission rate and key parameters of formaldehyde and volatile organic compounds (VOCs) from building materials" [41]. Chamber's experiments

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showed that a 10 °C rise in temperature resulted in 1.9 – 3.5 times increase in the formaldehyde emissions, and a 35% increase in relative humidity resulted in the increase of formaldehyde emissions by a factor of 1.8–2.6 [42]. A study on dry building materials showed that both temperature and humidity have tremendous influence on the rate at which formaldehyde is emitted from the materials [43]. A higher level of formaldehyde emissions was noticed when particleboard panels bonded with a UF-type resin were subjected to very high humidity and heat than the usual testing procedures [44]. Indoor formaldehyde concentration level increases with a corresponding increase in air temperature of the indoor environment [13].

2. MATERIALS AND METHOD

2.1. The Study Area

Rumuolumeni Community in Obio-Akpor Local Government Area was selected for this study. Rumuolumeni community is bounded on the north by Elio-parawo and Rumuokwuta communities, on the south by mile three Diobu, on the east by Creeks and Ogbogoro community, on the west by rivers and lies on latitude $4^{o} 65^{'} 44^{''}$ north and longitude $6^{o} 35^{'} 51^{''}$ east. The area is naturally inhabited by the Ikwerres, a sub-group of the Igbo cultural ethnicity and visitors from other tribes in Rivers State and people from other parts of Nigeria.

More so, as a part and one of the fastest growing communities in Obio-Akpor LGA, it plays host to some oil and gas service companies, the cement industry and others. Consequent upon this development, to accommodate the influx of new visitors to the area, more buildings of modern architectural designs with different colour of paints are being constructed. The study area is indicated in figure 1 with a black circle.

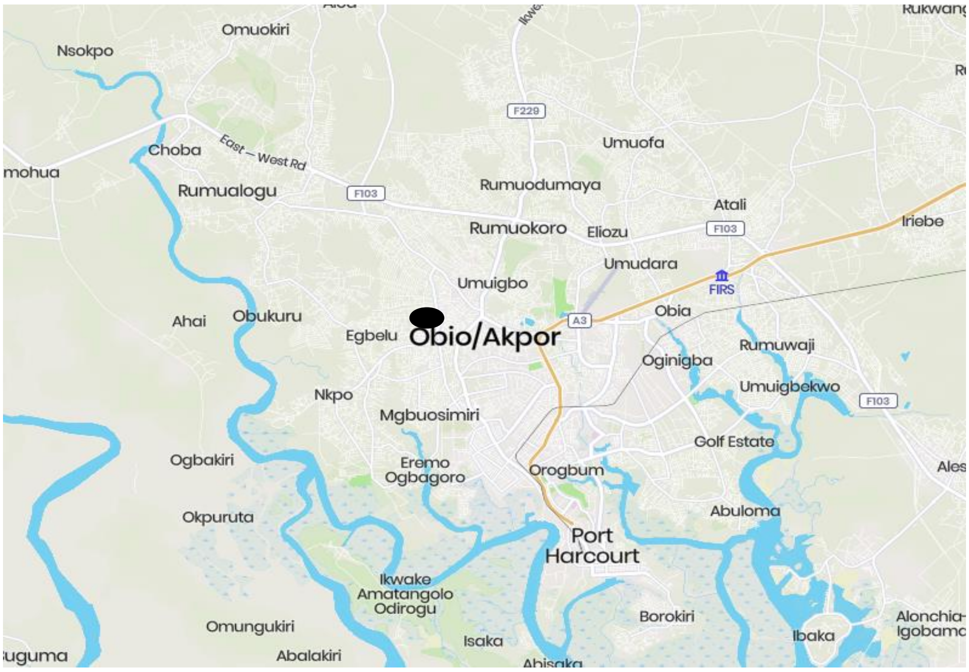

Figure 1. Map of Obio-Akpor Local Government Area Showing the Study Location with Black Spot

2.2. Materials

Materials employed in this study include formaldehyde concentration monitor, global positioning system (GPS), digital thermometer, digital hygrometer, measuring tape and stop clock.

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2.3. Method

Five different locations within Rumuolumeni community were selected for the study. In each of these locations, one newly painted building was chosen, making a total five buildings. Formaldehyde concentration monitor was positioned 1.5 meters above the floor of each of the newly painted buildings to determine the formaldehyde concentration levels every 30 minutes intervals for a period of three hours daily. The geographical locations, indoor relative humidity and temperature of the selected buildings for the period under study were also recorded. These were done for a period of two weeks.

3. RESULTS AND DISCUSSION

The global positions of the selected newly painted buildings are presented in Table 1.

Table 1. The Global Positions of the Selected Painted Buildings for the Study

Location	GPS Reading	
	North	**East**
Bigtree	04° 48'90"	06° 56'94"
Azumini	04° 48'83"	06°57'09"
Aker	04° 48'95"	06°57'20"
Eagle Clement	04° 48'59"	06° 56'37"
Erico	04° 48'52"	06° 56'32"

Figure 2 shows the mean indoor temperatures of the unpainted and painted buildings investigated for formaldehyde concentrations.

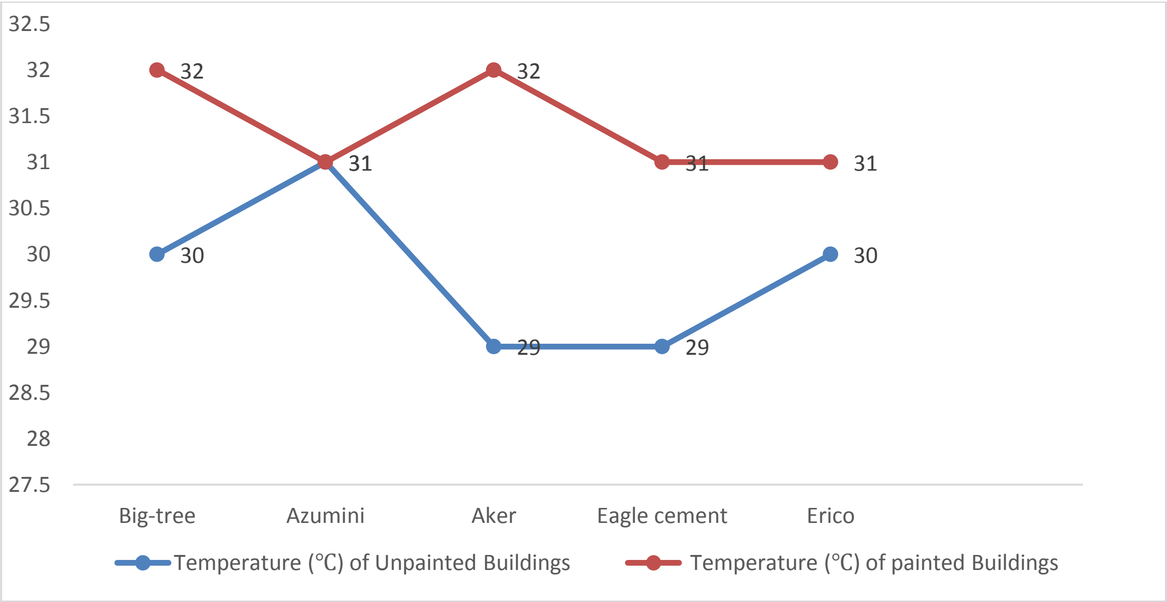

Figure 2. The Mean Temperatures of the the Selected Buildings

In figure 2, the temperature of the painted buildings (marked with orange curve) is generally higher than that of the unpainted buildings, except Azumini location, where both have the same mean temperature value of 31°C. This difference in temperature could be attributed to the painted walls acting as insulating surfaces and the nature of the building materials. More so, certain paints when applied to the walls have the potential to heat it [4].

Figure 3 is the mean relative humidity of the selected buildings under study.

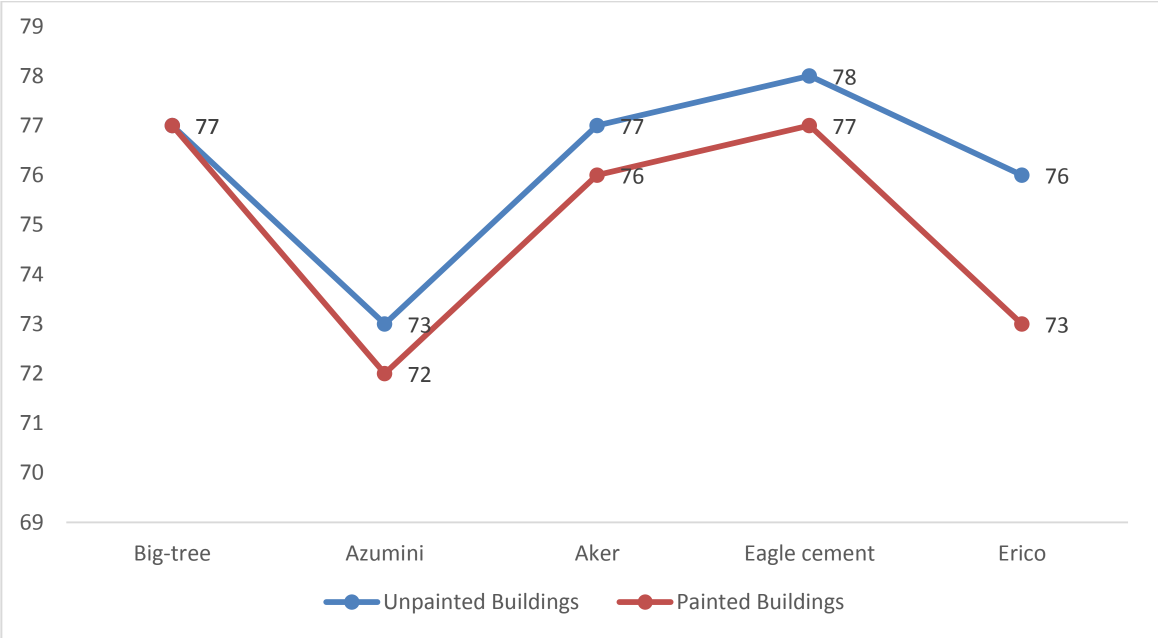

Figure 3. The Mean Relative Humidity of the the Selected Buildings

The differences in the mean values of the indoor relative humidity of these buildings could be attributed to the fact that when there is a rise in temperature, relative humidity tend to decrease. In figure 3, the relative humidity of the painted buildings is relatively lower than that of the unpainted buildings. Recall that in figure 2, the mean temperatures of the painted buildings are higher than the mean temperatures of the unpainted buildings. More so, the type of materials used in the construction of the individual building, the ventilation profile of the buildings, and the nature of the environment where these buildings are sited can as well contribute to the differences in their room temperatures and relative humidity.

Figure 4 is a bar-chart showing the measured mean formaldehyde concentration of the selected newly painted and unpainted buildings at different Locations for the period under study. In figure 4, generally, the painted buildings have higher formaldehyde emission concentration levels than those of unpainted buildings, except the unpainted building at Azumini location with concentration level of 0.58ppm, which equals the concentration level of the painted building at Erico location and higher than those painted buildings at Big-tree, Azumini, and Eagle Cement locations. The higher formaldehyde emission concentration levels of the painted buildings could be attributed to the painted walls. Similarly, the high formaldehyde concentration level of the unpainted building at Azumini location could be attributed to the type and number of decorative materials used in the buildings. Studies have shown that formaldehyde concentration is basically a function of the relative number of decorative materials used in the buildings [13]. More so, Zhai has reported that high levels of indoor formaldehyde pollution could emanate from

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interior decoration of buildings [11]. The painted building at Aker location has the highest formaldehyde concentration level of 0.060ppm followed by that of Erico (0.058ppm), while Big tree, Azumini, and Eagle Cement have the same concentration value of 57ppm. For the unpainted buildings, Azumini location has the highest formaldehyde concentration level (0.058ppm) followed by Big-tree (0.048ppm), while the unpainted building at Eagle has the lowest formaldehyde concentration level of 0.022ppm.

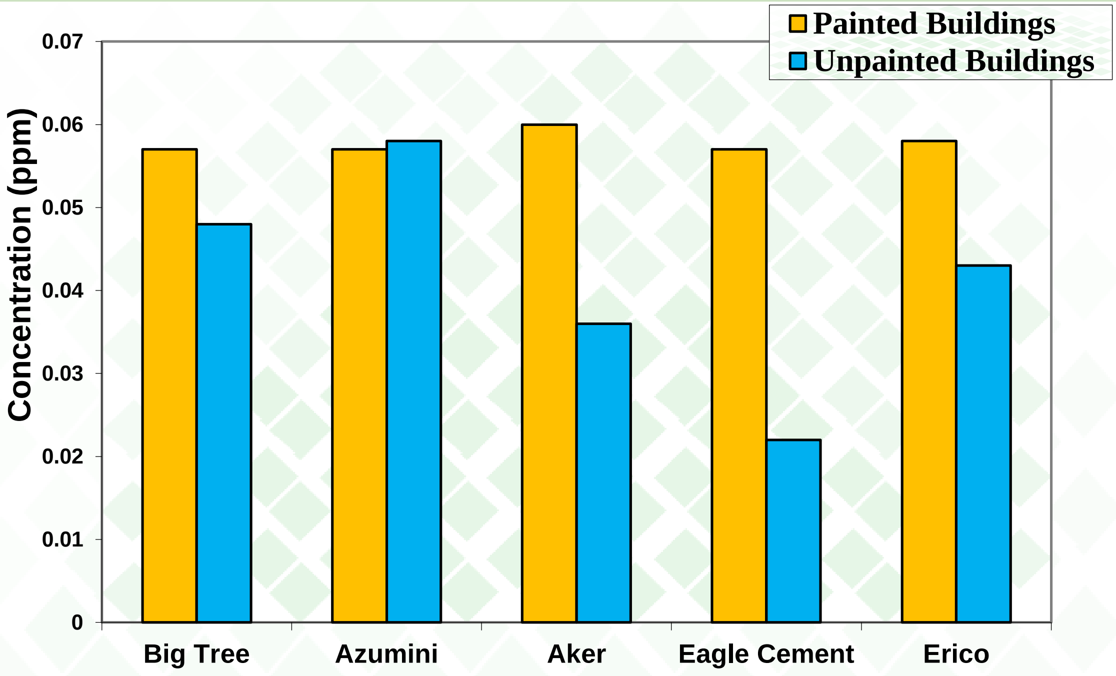

Figure 4. The Measured Formaldehyde Concentration Levels of the Selected Buildings at Different Locations

The mean values of 0.022ppm, 0.036ppm, 0.043ppm, 0.048ppm, 0.057ppm, 0.058ppm and 0.060ppm of formaldehyde concentration levels emitted by the selected painted and unpainted buildings for the period under study show that the average exposure limit to formaldehyde is in agreement with the permissible limits of 0.08 ppm and 0.1ppm established by World Health Organization (WHO) of 2018 and NIOSH of 2005 respectively. Similarly, the result of this study is also in agreement with the recommended levels permitted by Occupational safety and Health Administration (OSHA) of 2008 and American Conference of industrial Hygienists of 2006, which on their separate parts established permissible limits for formaldehyde in paints for residential and occupational environments to be 2ppm, 0.75ppm and 0.3ppm respectively. However, these values of formaldehyde concentration are higher than the "NIOSH recommended time-weighted average exposure limit of 0.016 ppm for workplaces", the "California Department of Health Services recommended guideline of 0.05 ppm for indoor air concentration" and the "ATSDR established "chronic inhalation minimal risk level (MRL) of 0.003 ppm (0.004 milligrams per cubic meter, mg/m^3) based on respiratory effects in humans". Going by the above data, there is perceived discrepancy, hence, the study agrees with the view of Tunga and others who alerted that, there exist no standard uniformity for tolerable limit of formaldehyde in paints and no unified unit as units including ppm, ppb & mg/m^3 are used [45].

4. CONCLUSION

It can be concluded that a painted indoor environment contributes to the increase in indoor air pollution levels due to the emission of formaldehyde compares to when it is not painted. This means that painted buildings, especially newly painted buildings will have poorer air quality than the unpainted buildings. Hence, the need to take adequate precautions against exposure to high level of formaldehyde concentration, especially in the indoor environment.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this research work.

References

[1] Salthammer, T., Mentese., S., Marutzky, R. (2010). Formaldehyde in the Indoor Environment. Chem. Rev., 110(4): 2536–2572. doi: 10.1021/cr800399g.

[2] Anthony, K.D. (2019). What is paint, definition, properties and components of paints. Civil seek Publishers.

[3] Gleeson, L. (2019). Ten reasons to paint your homes.Wall alive painting co. https://www.wallsalivepainting.com/10-reasons-to-paint-your-home.

[4] Photopoulos, J. (2020). The paint that eats pollutants and heat homes. Horizon, The European Research and Innovation Magazine.

[5] Srinivasan, H. (2021). 4 Neutral Colours that add value to your home. Real simple. Retrieved from https://www.realsimple.com/home-organizing/home-improvement/painting/paint-colors-increase-home-value.

[6] Ghamande, V.M., Nandangiri, O., Bagul,Y., Ponkshe, R., Kale,V., Bhatmule, R. (2016). Manufacturing of cow dung paint. International Journal of Advanced Research in Education & Technology, 3(2): 92–97.

[7] Kwon, S.C., Kim, I., Song, J, Park, J. (2018). Does formaldehyde have a causal association with nasophary-ngeal cancer and leukaemia? Ann Occup Environ Med., 30(1): 5. doi: 10.1186/s40557-018-0218-z.

[8] Protano, C., Buomprisco, G., Cammalleri, V., et al. (2021). The carcinogenic effects of formaldehyde occupational exposure: A systematic review. Cancers, 14(1): 165. doi: 10.3390/cancers14010165.

[9] WHO. (2010). WHO guidelines for indoor air quality: Selected pollutants. Regional Office Europe. https://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf.

[10] Lang, I., Triebig. G. (2008). Formaldehyde and chemosensory eye irritation: A controlled human exposure study. Regulatory Toxicology and Pharmacology, 50(1): 23–36. doi: 10.1016/j.yrtph.2007.08.012.

[11] Zhai, L., Zhao, J., Xu, B., Deng, Y., Xu, Z. (2013). Influence of indoor formaldehyde pollution on respiratory system health in the urban area of Shenyang, China. African Health Sciences,13(1): 137–143.

[12] Zhang, H., Qian, P.F & Zhu, M.Q. (2012). Emissions characteristics of formaldehyde from block board. The Chinese Journal of Process Engineering, 12(2): 335–339.

[13] Liu, L., Yu, X., Dong, X., Wang, Q., Wang, Y., Huang, J. (2017). The research on formaldehyde concentration distribution in new decorated residential buildings. Procedia Engineering, 205: 1535–1541. doi: 10.1016/j.proeng. 2017.10.2.

[14] Thorud, S., Gjolstad, M., Ellingsen, D., Molander, P. (2005). Air formaldehyde and solvent concentrations during surface coating with acid-curing lacquers and paints in the woodworking and furniture industry. J Environ Monit, 7(6): 586–591. doi: 10.1039/b418887j.

[15] Abdollahi, M., Hosseini, A. (2014). Formaldehyde. Encyclopedia of Toxicology (Third Edition), https:// www.sciencedirect.com /topics/earth-and-planetary-sciences/formaldehyde.

[16] Gupta, S.R.N. (2017). Polarographic determination of formaldehyde, acetaldehyde and propionaldehyde by calibration method. Int. Res. Journal of Science & Engineering, 5(1): 1–10.

[17] Trapp, D., Cooke, K., Fischer, H., et al. (2001). Isoprene and its degradation products methyl vinyl ketone, methacrolein and formaldehyde in a eucalyptus forest during the FIELDVOC'94 campaign in Portugal. Chemosphere - Global Change Science, 3(3): 295–307. doi: 10.1016/S1465-9972(01)00012-5.

[18] Subasi, N. (2020). Formaldehyde advantages and disadvantages: Usage areas and harmful effects on human beings. In M. Ince, O. K. Ince, & G. Ondrasek (Eds.), Biochemical Toxicology - Heavy Metals and Nanomaterials. IntechOpen. doi: https://doi.org/10.5772/intechopen.89299.

[19] Department of Climate Change, Energgy, the Environment and Water. (2022). Formaldehyde. https://www.dcceew.gov.au/environment/protection/npi/resource/student/formaldehyde.

[20] Olsen, D., Willson, B. (2011). The effect of retrofit technologies on formaldehyde emissions from a large bore natural gas engine. Energy and Power Engineering, 3(4): 574–579. doi: 10.4236/epe.2011.34071.

[21] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (1989). Diesel and gasoline engine exhausts and some nitroarenes. Lyon (FR): International Agency for Research on Cancer; 1989. (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 46.) https://www.ncbi.nlm.nih.gov/books/ NBK531294/.

[22] American Chemistry Council. (n.d). Formaldehyde occurs naturally and is all around us. American Chemistry Council. https://www.americanchemistry.com/chemistry-in-america/chemistries/formaldehyde.

[23] Zhang, L. (2018). Formaldehyde: Exposure, toxicity and health effects. The Royal Society of Chemistry. doi: 10.1039/9781788010269-00001.

[24] Tang, X., Bai, Y., Duong, A., Smith, M.T., Li, L., Zhang, L. (2009). Formaldehyde in China: production, consumption, exposure levels, and health effects. Environ Int., 35(8): 1210–24. doi: 10.1016/j.envint.2009.06.002.

[25] Mangum, J.G., Darling, J., Menten, K.M., Henkeh, C. (2008). Formaldehyde densitometry of starburst galaxies. Journal of Astrophysics, 673(2): 832–46.

[26] WHO. (2001). Formaldehyde. Air Quality Guidelines.WHO Regional Office for Europe, Copenhagen, Denmark. https://www.euro.who.int/__data/assets/pdf_file/0014/123062/AQG2ndEd_5_8Formaldehyde.pdf.

[27] Anderson, I. (1978). Formaldehyde in the indoor environment-health implications and the setting of standards. Institute of Hygiene University of Aarhus Denmark. https://www.aivc.org/sites/default/files/members_area/medias/pdf/Airbase/airbase_00512.pdf.

[28] Griesbaum, K., Miclaus, V., Jung, I.C. (1998). Paint and its components. Journal of Environmental Science & Technology, 32: 647.

[29] National Research Council. (1980). Formaldehyde - An assessment of its health effects on Humans. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/705.

[30] Ezratty, V., Bonay, M., Neukirch, C., et al. (2007). Effect of formaldehyde on asthmatic response to inhaled allergen challenge. Environ Health Perspect, 115(2): 210–4. doi: 10.1289/ehp.9414.

[31] NORD. (2007). Formaldehyde poisoning. https://rarediseases.org/rare-diseases/formaldehyde-poisoning.

[32] Andrzej, S., Dawid, S., Zaneta, Z., Monika, M. (2018). Formaldehyde removal by the internal wall paint-preliminary study. Wroclaw University Press.

[33] Elbeshbishy, E., Okoye, F. (2019). Improper disposal of household hazardous waste: Landfill/Municipal wastewater treatment plant. In Municipal Solid Waste Management IntechOpen. doi: 10.5772/intechopen.81845.

[34] Dar, A., Shafique,U., Anwar, J., Waheed-uz-Zaman., Naseer, A. (2016). A simple spot test quantification method to determine formaldehyde in aqueous samples. Journal of Saudi Chemical Society, 20(1): 352–356. doi: https://doi.org/10.1016/j.jscs.2012.12.002.

[35] FormerCare. (2019). Formaldehyde's many applications. https://www.formacare.eu/about-formaldehyde/applications/.

[36] CCOHS. (2022). Occupational Hygiene-Occupational Exposure Limits. OSH Answers Fact Sheet. https://www.ccohs.ca/oshanswers/hsprograms/occ_hygiene/occ _exposure_limits.html.

[37] Dictionary (BD) Editors. (2017). Formaldehyde. https://biologydictionary. net/formaldehyde/.

[38] Asare-Donkor, N.K., Kusi, A.J., Torve, V., Voegborlo, R.B,. Adimado, A.A. (2020). Formaldehyde exposure and its potential health Risk in some beauty salons in Kumasi Metropolis. J. Toxicol, 5: 8875167.

[39] Nielsen, G.D., Larsen, S.T., Wolkoff, P. (2010). Re-evaluation of the WHO (2010) formaldehyde indoor air quality guideline for cancer risk assessment. Arch Toxicol., 91: 35–61. doi: 10.1007/s00204-016-1733-8.

[40] Stephanie, P. (2011). Oldest human paint-making studio Discovered in Cave. Live Science Publishers, U.S.A.

[41] Huang, S., Xiong, J., Cai, C., Xu, W., Zhang, Y. (2016). Influence of humidity on the initial emittable concentration of formaldehyde and hexaldehyde in building materials: Experimental observation and correlation. Sci Rep., 6: 23388. doi: https://doi.org/10.1038/srep23388.

[42] Parthasarathy, S., Maddalena, L., Russel, L.M., Apte, G.M. (2011). Effect of temperature and humidity on formaldehyde emissions in temporary housing Units. Journal of the Air & Waste Management Association, 61(6): 689–695. doi: 10.3155/1047-3289.61.6.689.

[43] Shan, Z., Hong, L., Yong, D., Yuxin, W. (2019). The effects of temperature and humidity on the VOC emission rate from dry building materials. IOP Conf. Series: Materials Science and Engineering, 609: 042001. doi: 10.1088/1757-899X/609/4/042001.

[44] Frihart, C.R., Wescott, J.M., Chaffee, T.L., Gonner, K.M. (2012). Formaldehyde emissions from urea-formaldehyde-and no-added-formaldehyde-bonded particle board as influenced by temperature and relative humidity. Forest Production Journal, 62(7/8): 551–558. doi: https://doi.org/10.13073/ffpj-d-12-00087.1.

[45] Tunga, S., Sibel, M., Rainer, M. (2010). Formaldehyde in the indoor environment. Chem Rev., 110(4): 2536–2572.