Journal of Air Pollution and Health (Summer 2020); 5(3): 193-200

Original Article

Available online at http://japh.tums.ac.ir

Implications of portable gasoline electricity generators on residential indoor air quality

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ARTICLE INFORMATION

Article Chronology:
Received 19 June 2020
Revised 27 July 2020
Accepted 03 September 2020
Published 29 September 2020

Keywords:
Air quality; Pollutants; Generators; Residences; Indoor

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ABSTRACT:

Introduction: Toxic gases emitted from electricity generating plants used for energy production process diffuse in the environment thereby causing environmental air pollution. The effect of the installation and usage of portable gasoline electricity generating plants at the balcony of different households on the indoor air quality was assessed in this study.
Materials and methods: The data collected were the air quality chemical composition variables which include carbon-dioxide, formaldehyde, total volatile organic compounds, coarse (PM_{10}), and fine ($PM_{2.5}$) particulate matters at the indoor of the households in Abeokuta metropolis, Ogun state, Nigeria. Physical measurement techniques used for the data collection was through the instrumentation design of two air quality testers, models WP6910 and ZN-202S. The indoor air quality assessment followed the generator nighttime usage routine between the hours of 6:30 – 10:00 pm at a measurement height of 1.3 m and the center in the living rooms of the residences assessed.
Results: The analysis of the data obtained showed that the mean values for each of the air quality parameters obtained during generator usages were significantly higher when compared to the indoor air quality parameters before generator usages at $p<0.05$. The air pollutant levels before and during generator usages were within the established safe standard air quality limit by the world health organization.
Conclusion: However, for the installation of a portable electricity generator at the residents' balcony, it is recommended that the generators should be adapted with an emission reduction device for the exhaust composition amelioration to avoid possible accumulation effect over time.

Introduction

The residential sector is one of the sectors in Nigeria's economy characterized by high energy consumption and high ownership and operation of private generators. The high rate of generator ownership and operation according to studies is caused by the ravage of the limited access to quality and quantity of electricity in the sector [1-3]. This actively contributes to the direct pollution of the environment [3-5]. Portable generators being adapted with two-stroke engines are marked by incomplete combustion processes thereby emit-

Please cite this article as: Azodo AP, Omokaro I, Canice Mezue T. Implications of portable gasoline electricity generators on residential indoor air quality. Journal of Air Pollution and Health. 2020; 5(3):193-200.

ting completely combusted gases and unburnt hydrocarbons. The installation of these portable generator challenges at the different households according to a study found in the literature is space issues and theft considerations, despite the associated environment pollutants it emits [6]. A study revealed that increased intensity of air pollutants generated on the outdoor environment penetrates the indoor environment thereby influencing the quality of the indoor air [7]. These pollutants usually have higher concentrations at the source and then diffuse in the environment thereby affecting the whole environment. The composition and intensity of the air pollutant released are dependent on the causation factor.

Considering the daily average quantity of air uptake by humans (12 kg), its connection to the quality of life, and the restful role of the residential sector to humans [8], it has become imperative that the quality of air uptake in the households be monitored [9]. When the concentration of the air quality compositions discharged into the atmosphere is above the regulatory permissible limits, it affects both the human health and the environment [10, 11]. The recommended daily average indoor air quality guideline values for $PM_{2.5}$ and PM_{10} concentrations established by the world health organization above which will be a concern to human health is 0.025 and 0.050 mg/m^3 respectively [12]. For formaldehyde, it is 0.1 mg/m^3 (0.08 ppm) for a total period of 30 min for short and long term lifelong exposure [13]. The varying range of formaldehyde from 0.05 to 0.5 mg/m^3 was reported in a study as odor thresholds [14]. The Commission of the European Communities (1990) noted that 0.1 mg/m^3 of formaldehyde (HCHO) in the indoor environment causes eye irritation, at 0.5 mg/m^3 biting sensation in the nose, danger to life (37.5 mg/m^3), and death (125 mg/m^3) [15]. Carbon dioxide (CO_2) is another concerning air pollutant in an indoor environment. Its presence in the environment causes oxygen deficiency and since it is heavier than air, it accumulates at the lower spaces of the indoor environment, which at very high concentrations can pose a health risk [16]. Increased inhaled carbon dioxide increases pulmonary ventilation [17]. The average occupied indoor spaces CO_2 concentration range guideline for good air exchange, ventilation, and comfort should be less than 1100 ppm [18]. The recommended minimum ventilation rate of indoor CO_2 above which there are sick building syndrome symptoms in an indoor environment is 10 L/s. This corresponds to a steady-state indoor concentration of approximately 870 ppm [19]. Organic gases having similarity in their chemical composition but not easily distinguishable classified as TVOC also has a direct link with the indoor air quality. TVOC encompasses a wide range of different organic chemicals and not a representation of a single gas, the concurrence limit adopted for an indoor TVOC by environmental and health concerned standard organizations such as Environmental Protection Agency (EPA), World Health Organization (WHO), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is <500 µg/m^3 [20]. Most reported total volatile organic compounds concentrations in locations other than industrial environments found in the literature were below 1 mg/m^3. Only a handful exceeded 25 mg/m^3. In ensuring the acceptability of indoor air quality and suitability of airflow exchange within a residential indoor space, the indoor environment air quality compositions be evaluated and be kept to at its barest minimum for the wellbeing of the occupants. Hence this study assessed the effect of using portable gasoline electricity generating plants for the energy production process for its installation at the balcony on the residential indoor air quality.

Materials and methods

The physical measurement sampling technique was used in the air quality assessment of the households that uses gasoline powered electricity generating plants. All assessment was carried out from April – September 2019 in Abeokuta metropolis, Ogun state, Nigeria. The indoor air quality assessment in this study followed the generator night time usage routine between the hours of 6:30 – 10:00 pm in each of the residences assessed. The instrumentation design for this study was a combination of air quality testers, models JBL-B600 (Shenzhen Dapeng Trading Co., Ltd., China) and ZN-202S (Shenzhen Zene Industry Co., Ltd., China). The air quality parameters assessed included Carbon dioxide (CO_2), formaldehyde (HCHO), total volatile organic compounds (TVOC), Particulate matters ($PM_{2.5}$ and PM_{10}). The microclimatic condition of the indoor environment such as air circulation, ambient temperatures and relative humidity were monitored using digital anemometer of model GM816 (Shenzhen XRC Electronics Co., Ltd. Mainland China) and digital LCD thermometer hygrometer (At finger technology Co., Ltd China (Fujian) respectively. The age, capacity and generator maintenance were not considered. Following the postulation in studies that season, wind speed, temperature and humidity influences air pollutants' emissions, concentration, dilution, transport, and re-suspension the air quality assessment was carried out at the indoor environments of the residences during the rainy season (April – September) temperature range of 20 – 23°C, 67 – 73% relative humidity and still air circulation (0 m/s) [21-25]. The major focus of this study featured in all the households assessed was the installation of the generators at the balcony of the households both bungalows and storey buildings. To determine the operational effect of the generators on the indoor air quality of the residences assessed, the bio-effluent and anaerobic effect were checked as it was ensured that the number of individuals in both measurement periods was the same. At each of residences covered in this study, the air quality assessment was conducted 15-30 min before the generators were powered on and 30-60 min into the usage of the generators at each of the households. The air quality parameters were assessed and recorded three times before and during the generator usage sampling time of 5-10 min at the intervals of 30 s from each evaluation. The total numbers of samplings at each residence was six. For each of the households, the rooms assessed were the closest room to the balcony where the generator was placed, which in this study all were the living rooms. The living rooms are the central room in all residences where family members spend time together [26]. The window and door openings were observed to be the users' usage routine (either open or closed). The air quality data was obtained at an assessment height of 1.3 m from the room floor using a purposeful designed portable platform and at the center in the living rooms [12, 19]. The proposed residents were contacted and informed of the study, its purpose, procedure, and assurance of confidentiality using a letter format. This was hand-delivered to the households' on face to face contact with the researcher. The air quality assessment was conducted only where permission was granted. The sampling and interval timing was done using a digital professional handheld LCD stopwatch (Shenzhen super deal Co. Ltd, China). Since the emission from the generators are continuous and varying for the period in which the generators were used, the air quality parameters measured and registered were evaluated for mean air quality in the residences assessed for a single mean value that will reflect the CO_2, TVOC, HCHO, $PM_{2.5}$, and PM_{10} data obtained at residences assessed. A paired samples *t*-test analysis was used on the mean values of the measured and registered air quality parameters for the comparisons between the before and during generator usages to determine the operational effect of the generators on the indoor air quality of the residences assessed. The statistical difference of the mean values between before and during generator usages was set at $p < 0.05$ for significance. Statistical Package for Social Science (SPSS) version 16.0 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel 2016 (Microsoft Corporation Technology Company, Washington, US) software were used for the statistical evaluation of the air quality data obtained.

Results and discussion

The data samples obtained from 57 residences surveyed were subjected to descriptive statistical analysis. The result showed that during the generator usages by the households, the CO_2 exposure means±SD was 631±115 ppm was statistically higher than the air quality of the residences before generator usage (534±14 ppm) (Table 1). The paired samples t-test carried out on the CO_2 data obtained gave $t(56)=8.474$, at a p-value of 0.000 which is less than the set level of significance ($p<0.05$) (Table 1). The comparison of the TVOC air quality parameters showed that before the generator usage the residences assessed had statistically lower TVOC values (0.095±0.022 mg/m^3) compared to the TVOC values during generator usage (0.187±0.185 mg/m^3), $t(56)=3.740$, $p=0.000$. The mean HCHO air quality parameter of the indoor residences before generator usage in this study was 0.013 ± 0.003 mg/m^3, while, during the generator usage, it was 0.038 ± 0.038 mg/m^3 (Table 1). There was a statistical difference between the generator before and during usage periods significant at $p=0.000$. The mean±SD of $PM_{2.5}$ air quality parameter of the residence assessed before generator in this study was 3.248±1.491 µg/m^3 which were statistically lower than the value obtained during generator usage (9.266±3.899 µg/m^3) (Table 1). The PM_{10} air quality parameter in the residences assessed also recorded higher mean value (8.390±2.715 µg/m^3) during generator usage when compared to the generator usage before the generator usage (13.861±4.254 µg/m^3) $t(56) = 4.533$, $p = 0.000$ (Table 1).

The air quality composites occur naturally, while the unhealthy level is usually triggered by anthropogenic activities. The anthropogenic source assessed in this study is a portable gasoline generator with consideration to the installation location at the balcony, knowing that the combustion of the engine and its exhaust produces air pollutants with higher concentration at the source and then diffuses in the environment. From the analysis of the result obtained in this study, the mean concentration of the CO_2 parameter in the indoor air quality environment assessed was an average of 534±14 ppm before and 631±115 ppm after generator usage (Table 1). The significant difference

Table 1. Statistical analysis of the indoor air quality parameters before and during generator usage

Air quality parameters	Before generator usage			During generator usage			Paired samples *t*-test analysis		
	Max	Min	Mean ± SD	Max	Min	Mean ± SD	T	df	P – value
CO_2 (PPM)	575	506	534 ± 14	974	535	631 ± 115	8.474	56	0.000
TVOC (mg/m^3)	0.140	0.038	0.095 ± 0.022	1.230	0.042	0.187 ± 0.185	3.740	56	0.000
HCHO (mg/m^3)	0.020	0.005	0.013 ± 0.003	0.175	0.008	0.038 ± 0.038	4.901	56	0.000
$PM_{2.5}$ (µg/m^3)	6.8	1	3.248 ± 1.491	20	2	9.266 ± 3.899	5.923	56	0.000
PM_{10} (µg/m^3)	15.3	5	8.390 ± 2.715	24.3	6	13.861 ± 4.254	4.533	56	0.000

Carbon dioxide: CO_2, Formaldehyde: HCHO, Total Volatile Organic Compounds: TVOC, Particulate matters: coarse (PM_{10}) and fine ($PM_{2.5}$)

in the CO_2 level in both cases is an indication of the negative impact of the generator usage and its installation location which a redress as the presences of CO_2 in a space displaces the oxygen in that space, accumulate at lower spaces in the indoor thereby constituting the major inhaled gas by occupants [16]. Taking into consideration that increased inhaled carbon dioxide increases pulmonary ventilation, the acceptability of indoor air quality and suitability of airflow exchange is an indication of sufficient fresh air within the indoor spaces of a building [17, 27]. Relating the CO_2 exposure before and during the generator usage at the indoor of the residences on the typical indoor air quality guidelines stipulated by ASHRAE Standard 62-2001 for CO_2 parameter for an occupied indoor space, it was found that the CO_2 exposure was within good air exchange, comfort and ventilation criteria. The compositions of particulate matter which are nitrates, sulfates, organic chemicals, inorganic substances, metals, soil or dust particles, sodium chloride, black carbon, water, and allergens suspended in the atmosphere are directly linked to their potential for causing health problems. The analysis of the particulate matter ($PM_{2.5}$ and PM_{10}) before and during generator usages showed that the level of differences in the exposure rate in both assessment periods was significant. This study backed observations in the literature that particulate matter in the indoor among other sources is a factor of fuel-based lighting [28-29]. Fine particles ($PM_{2.5}$) pose the greatest health risk on the human respiratory system. These fine particles can get deep into the human lungs and as such sediment in the alveoli; some may even get into the bloodstream. The particulate matter sediment in the alveoli narrows the airways and reduces the air in and out flowability of the lungs [30]. The particulate matter below 2.5 µm ($PM_{2.5}$) can also affect the heart [31-36]. The coarse particles of an aerodynamic diameter of 10 µm (PM_{10}) have the eyes, nose, and throat irritation tendencies. In other to ascertain the general acceptable indoor particulate matter parameter in the indoor air quality composition, the $PM_{2.5}$ and PM_{10} data obtained in this study was subjected to the indoor air quality recommended guideline values for daily average PM_{10} and $PM_{2.5}$ concentrations established by the world health organization above which will be a concern to human health, these were observed to be within the safe limits before and during generator usage periods. Portable generators being adapted with two-stroke engines are anthropogenic sources classified under direct emissions, especially for the production of formaldehyde. Formaldehyde emission irrespective of sources is a prominent factor in sick-building syndrome as its emission as low as less than 0.5 mg/m^3 irritates the eyes, the nasal mucosa, mucous membranes in the throat, causes headache and dizziness with carcinogen potentials. Knowing that other items in the indoor environment contribute to the formaldehyde emission in the households, the assessment of the presence of formaldehyde in the indoor environment before the generator use accounted for those other sources. The formaldehyde detection as a result of the generator usage gave a mean average value of 0.038±0.038 mg/m^3. The mean value of formaldehyde obtained during generator usages in the residences assessed was higher when compared to the air quality parameters before generator usage and it was significant at $p = 0.000$. The range of formaldehyde observed in this study when compared to the standard air quality ranges for an indoor environment was found to be within for good human health air exchange, ventilation, and comfort safe limits when considered for a single and repeated exposure. The total volatile organic compounds exposure as a result of the generator usage at the residences was 0.187±0.185 mg/m^3. This TVOC concentration in this study has no single and repeated exposure potential effect as the average value obtained was less than 1 mg/m^3. However, the statistical difference before and during generator usage is significant, which is an indication of the penetration of un-burnt hydrocarbon into the indoor space of the residence.

Conclusion

The effect of portable gasoline electricity generating plant installed at the balcony of people's homes for energy production process on the indoor air quality assessed using physical measurement techniques has shown that for each of the air quality parameter CO_2, TVOC, HCHO, $PM_{2.5}$, and PM_{10}, the mean values obtained during the generator usages in the residences assessed were higher when compared to the air quality parameters before generator usage. The operational effect of the generators on the indoor air quality parameters of the residences was significant though within the safe limit. This, therefore, necessitates that for the installation of a portable electricity generator at the balcony, the generators should be adapted with an emission reduction device for the exhaust composition amelioration. Considering the length of time people spend at home, it is important to subjectively evaluate the exposure rate effect of the gases emitted from electricity generating plants on the residents.

Financial supports

This study was self sponsored by the authors

Competing interests

The authors declare no competing interests

Acknowledgements

The authors appreciate the residents for their cooperation in the data process of this study

Ethical considerations

Every document consulted during the write up phase of this study was acknowledged. No household was coerced into participation as participation was voluntary. The data presented in this study were obtained by the physical measurement survey. This paper has not been published in anywhere neither is it under consideration in another journal.

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